EARTHQUAKE HAZARD IN THE MIDDLE EAST:

AN EVALUATION FOR INSURANCE AND REINSURANCE PURPOSES

by

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ABSTRACT

This study provides an analysis of earthquake hazard in the Middle East for insurance and reinsurance purposes. The analysis incorporates important lessons learned from the 1985 Mexican earthquake. It has the following components:

a) An in-depth examination of the Mexican earthquake. This has highlighted the strong influence of superficial geology in controlling exposure to earthquake hazard, and of building type and height in controlling vulnerability to damage;

b) An analysis of the escalating earthquake risk in the Middle East. It is concluded that this is attributable to rapid rates of population growth, urbanisation and economic expansion, and to the development of marginal areas that are more exposed to earthquakes;

c) A regional analysis of the distribution of earthquake hazard, based on 20th century data and a catalogue of historical earthquake activity that has been compiled during the research programme. It is shown that the areas of greatest hazard tend to coincide with the most densely inhabited parts of the region. The analysis has also provided evidence of temporal fluctuations in seismic activity between contiguous tectonic zones;

d) The presentation of a new scheme for earthquake hazard zonation, which is designed to meet the specific requirements of insurers and reinsurers. An evaluation of this scheme, using Israel as a case-study, has proven its worth as a basis for detailed

insurance-oriented examinations of earthquake hazard and risk;

e) A discussion of earthquake risk control. It is concluded that the data and techniques presented in this study can be used to derive hazard and risk assessments that are more accurate than those currently available to the insurance industry. By using such assessments to control its own vulnerability to earthquake loss, the industry can help to stem the escalation of risk that has recently been witnessed in the Middle East.

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Martin R.Degg (Nottingham, July, 1988)

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CHAPTER 1. BACKGROUND TO THE STUDY

"Once an earthquake region, always an earthquake region" (Bailey Willis, 1928; p.103).

1.1 INTRODUCTION

The Middle East has a long and continuous history of earthquake disasters. Recent earthquakes in the region, such as those at Agadir (1960), El Asnam (1980) and Dhamar (1982), have served to confirm that this threat still exists. Ali (1985) has been able to show that earthquakes threaten more large population centres in the region than any other type of natural hazard (see Table 1.1).

The Middle East has experienced considerable economic growth in recent decades. As a direct consequence of this, the vulnerability of the region to large earthquake losses has increased. This fact has not gone unnoticed by the insurance industry, which is becoming increasingly concerned about the escalating earthquake risk in the region.

Accurate assessments of the distribution, severity and frequency of earthquakes in Middle Eastern countries are often lacking. Those assessments that are available frequently fail to delineate the severity of the hazard in terms that are of relevance to the insurance industry. Insurers and reinsurers therefore lack the necessary information on which to base reliable risk assessments,

TABLE 1.1

The Exposure of Major Middle Eastern Cities* to Natural Hazards

	EARTHQUAKE			FLOOD			OTHER			
	Low exposure	Moderate exposure	High exposure	River	Coastal	Tsunami	Shifting Sand	Saline Soil etc.	Landslide	Gales
Number of towns (exceeding 100,000 population) exposed to natural hazards	129	33	1	11	35	24	47	61	12	19
TOTAL		163			70			139		

*Israeli cities excluded from the analysis

Source: Ali (1985;p.142)

and find it very difficult to control their exposure to earthquake loss.

The present study hopes to help insurers overcome some of these problems. The purpose of this introductory chapter is to summarise the major research objectives, and the methodology used. A brief account of the structure and contents of subsequent chapters is given, together with a short glossary of important terms as they are used in the study.

1.2 OBJECTIVES OF THE STUDY

The aim of this study is to provide an analysis of earthquake hazard in the Middle East for insurance and reinsurance purposes. A primary requirement of the work is that it should provide the sorts of data (and maps), that will enable insurers and reinsurers to assess exposure to earthquake hazard more accurately than is possible at present (thereby enabling them to control their commitments).

Despite the limited amounts of quantitative data available for the region, relatively detailed assessments of earthquake hazard can still be achieved using general information that is more easily obtained. Such an approach to earthquake hazard assessment is applicable not only in the Middle East, but also in many other developing regions of the world where seismo-geological data are limited (or access to these data is restricted).

1.3 METHODOLOGY OF STUDY

In order to assess exposure to earthquake hazard, it is necessary to have as complete an understanding as is possible of the elements that serve to control the severity of the hazard. The best way to identify these elements, and to obtain quantifiable data concerning them, is to analyse the actual situation created by an earthquake disaster. It is for this reason that the present study includes a detailed analysis of the 1985 Mexican earthquake (based upon field investigations). Although obviously outside the Middle Eastern region, this earthquake disaster occurred during the research programme. The opportunity was therefore taken to study it at first hand.

The Mexican earthquake has served to provide a number of valuable guidelines concerning the best way to approach a regional evaluation of earthquake hazard and risk. In particular, it has highlighted several very important factors that need to be taken into consideration when trying to zone earthquake hazard. These findings have been applied (wherever appropriate) to the Middle Eastern analysis.

Most of the data concerning the Mexican earthquake were obtained first hand. In contrast the Middle Eastern research has, by necessity, relied mainly upon data derived from a wide variety of secondary sources. Earthquake hazard is usually delineated on the basis of data concerning previous earthquake occurrences. In this context, it is fortunate that the Middle East has one of the longest documented histories in the world. Advantage of this has been taken, by compiling a comprehensive catalogue (and computerised database) of historical earthquake activity in the region (i.e. activity prior to the 20th century). These data have formed the basis of much of the Middle Eastern analysis, and should also provide a firm foundation for future research concerning earthquake hazard in the region.

Catalogues of 20th century earthquake activity in the Middle East are already in existence, and are relatively easily obtained. For example, from the B.G.S. (Edinburgh) and the U.S.G.S. (Colorado). By combining these data with the historical catalogue (as compiled during the research programme), it has been possible to summarise knowledge concerning earthquake activity in the region during the last two millennia. The data have provided the basis for a regional analysis of earthquake hazard in the Middle East. They have served to identify the parts of the region that are most exposed to the earthquake threat. It is within these areas that insurers and reinsurers need to be most wary of their commitments.

A technique of earthquake hazard zonation has been developed for application in the hazardous areas. This is designed to meet the specific needs of the insurance industry, and incorporates lessons learned from the Mexican earthquake. The technique has been used to produce a hazard map of a Middle Eastern country (i.e. Israel). Ways of incorporating this zonation in an insurance-oriented analysis of hazard and risk in the country have then been examined. Field investigations were conducted in Israel to assist the production of the hazard zonation, and to examine the accumulation and vulnerability of risks within specific hazard zones.

In addition to scientific investigations, the research programme has necessitated direct liaison with insurers and reinsurers. The purpose of this has been to ascertain the specific requirements of the insurance industry. Meetings have been held with representatives of various U.K. and foreign companies (i.e. Swiss, Mexican and Egyptian). Close correspondence has also been maintained with a number of natural catastrophe reinsurers working in large European reinsurance companies.

1.4 CHAPTER STRUCTURE

The study has been subdivided into 10 chapters and 2 appendices. Chapter 2 is devoted to the 1985 Mexican earthquake, and summarises the major findings of the event. The implications of these for earthquake hazard assessment in other seismic regions (including the Middle East) are discussed. By way of introduction to the Middle Eastern analysis, Chapter 3 describes the area of investigation and examines reasons for the recent escalation of earthquake risk within it. The implications of these for the insurance industry are discussed. The chapter concludes with a brief description of the methodology of earthquake hazard assessment that has been applied to the region.

The Middle Eastern hazard analysis is subdivided into two parts. Part A comprises chapters 4 to 6 inclusive, and presents a regional examination of the distribution and severity of earthquake hazard. Chapter 4 analyses the tectonic setting and twentieth century earthquake activity of the region, while Chapter 5 discusses the historical seismicity. Chapter 5 is, in fact, subdivided into two parts. Part One describes the way in which an historical earthquake catalogue of the Middle East has been compiled, while Part Two contains an analysis of the data in the catalogue. Chapter 6 uses the recent and historical earthquake data to present a comprehensive analysis of the distribution of earthquake hazard in the Middle East. Parts of the region that are exposed to the earthquake threat are identified, and the current potential for earthquake-induced losses in these areas is assessed. The chapter concludes with an analysis of fluctuations in the seismicity of different Middle Eastern countries through time.

Part B of the Middle Eastern analysis comprises Chapters 7 and 8. It describes a technique of hazard zonation that has been developed for application in the areas that are exposed to earthquakes. Chapter 7 discusses the way in which this technique has been designed to meet the specific requirements of insurers and reinsurers, and in Chapter 8 the technique is applied to Israel. A hazard map of the country is produced, and is used as the basis for an insurance-oriented analysis of earthquake hazard and risk.

Chapter 9 concludes the study with a discussion of earthquake risk control. The procedures presently employed by the insurance industry to assess and control the risk are described, and it is shown how the data and findings of the present study can be incorporated in these. A possible new approach to the problem is also suggested. The chapter closes with a consideration of the role of the insurance industry in helping to stem the escalation of earthquake risk that has been witnessed in regions like the Middle East.

In Chapter 10 the major conclusions of the study are summarised, and some suggestions for further research are given.

The appendices contain the historical earthquake catalogue, which has been divided into two parts. Appendix A contains the catalogue for the eastern part of the region, whilst Appendix B contains that for the western part. Each appendix is subdivided into four sections: The first contains the catalogue, the second provides an index of countries in the catalogue, the third provides an index of hazards associated with the earthquakes, and the fourth lists the data sources.

1.5 GLOSSARY

The purpose of this section is to define some important terms as they are used in the study.

EPICENTRE - the point on the Earth's surface that lies directly above the focus of an earthquake.

FOCUS - the point of origin of an earthquake within the crust of the Earth.

FOCAL DEPTH - the shortest distance between the focus of an earthquake and the surface of the Earth (the epicentre). Earthquakes are categorised according to their focal depth as follows:

Shallow	(<70km)
Intermediate	(70-300km)
Deep	(>300km)

Earthquake HAZARD - the expected severity and (or) frequency of earthquake ground motions. Hazard is greatest in those areas where the severest motions occur most often.

INTENSITY - a measure of the effects of an earthquake on humans, structures and the surface of the Earth. The intensity at a point depends not only upon the strength of the earthquake (magnitude), but also upon distance from the epicentre and local geological conditions. A number of intensity scales exist, of which the Modified Mercalli scale (MM) is the most commonly used. This has twelve grades denoted by Roman numerals.

ISOSEISMAL LINE - a line connecting points on the Earth's surface of equal earthquake intensity. It usually encircles the earthquake epicentre.

MAGNITUDE - a measure of the strength of an earthquake (i.e. the total energy released by the event). It is determined by seismographic observations and calibrated using the Richter scale. This scale is logarithmic and open-ended. The largest earthquake magnitude recorded to date is 8.9.

MICRO-EARTHQUAKE - an earthquake of magnitude less than 4.0 on the Richter scale.

Earthquake RISK - the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to earthquakes. Within an area of high earthquake hazard, earthquake risk can vary considerably according to the distribution, value and vulnerability of elements exposed to the earthquake threat.

VULNERABILITY - the degree of loss that can be expected as a result of the occurrence of a given severity of earthquake ground motion.

CHAPTER 2. THE 1985 MEXICAN EARTHQUAKE - ANATOMY OF AN EARTHQUAKE DISASTER

2.1 INTRODUCTION

The 1985 Mexican earthquake ranks foremost amongst the most disasterous earthquakes to have affected the insurance industry. In terms of overall insurance loss, the event is superseded only by the Tokyo earthquake of 1923, and the San Francisco earthquake of 1906 (Munich Re., 1986).

Subsequent to the earthquake, seven weeks field-work was carried out in Mexico. The main aim of this was to gather enough data to enable those factors which control the severity of earthquake impact upon a country to be identified. Data of this type, which lead to a greater understanding of earthquakes and their effects, are a primary requirement in the delineation of seismic hazard and risk. The lessons learned from this study of the Mexican catastrophe, will therefore subsequently be applied to the analysis of earthquake hazard in the Middle East.

The chapter is divided into three parts. Part One summarises pertinent background information concerning the earthquake. Part Two provides a detailed analysis of the damage in Mexico City, and Part Three considers engineering and insurance aspects of the event.

Part One begins by describing the regional setting of Mexico. Following this, the tectonic setting of the country is reviewed, and historical and 20th century earthquake activity summarised. The repeat times of large earthquakes in Mexico are analysed, and the possible size and location of some future earthquake events is discussed. A description is then given of the seismology of the 1985 event, and of the distribution of damage in the epicentral region. Part One concludes with a review of the damage experienced in Mexico City.

Part Two begins by describing the geological setting of Mexico City. The procedures used to analyse damage in the city are then described, and the results of these investigations summarised. Possible reasons for the observed distribution and severity of damage are given. In this context, the influence of subsoil conditions is discussed in detail, as is the vulnerability to damage of different types and heights of construction.

Part Three commences with a description of the common causes of building failure in Mexico City. Insurance and reinsurance aspects of the earthquake are then discussed, including an analysis of amendments that have been made to the Mexican earthquake tariff subsequent to the disaster. The chapter concludes with a summary of the major findings of this study, and an evaluation of the implications of these for earthquake hazard and risk assessment in other parts of the world (including the Middle East).

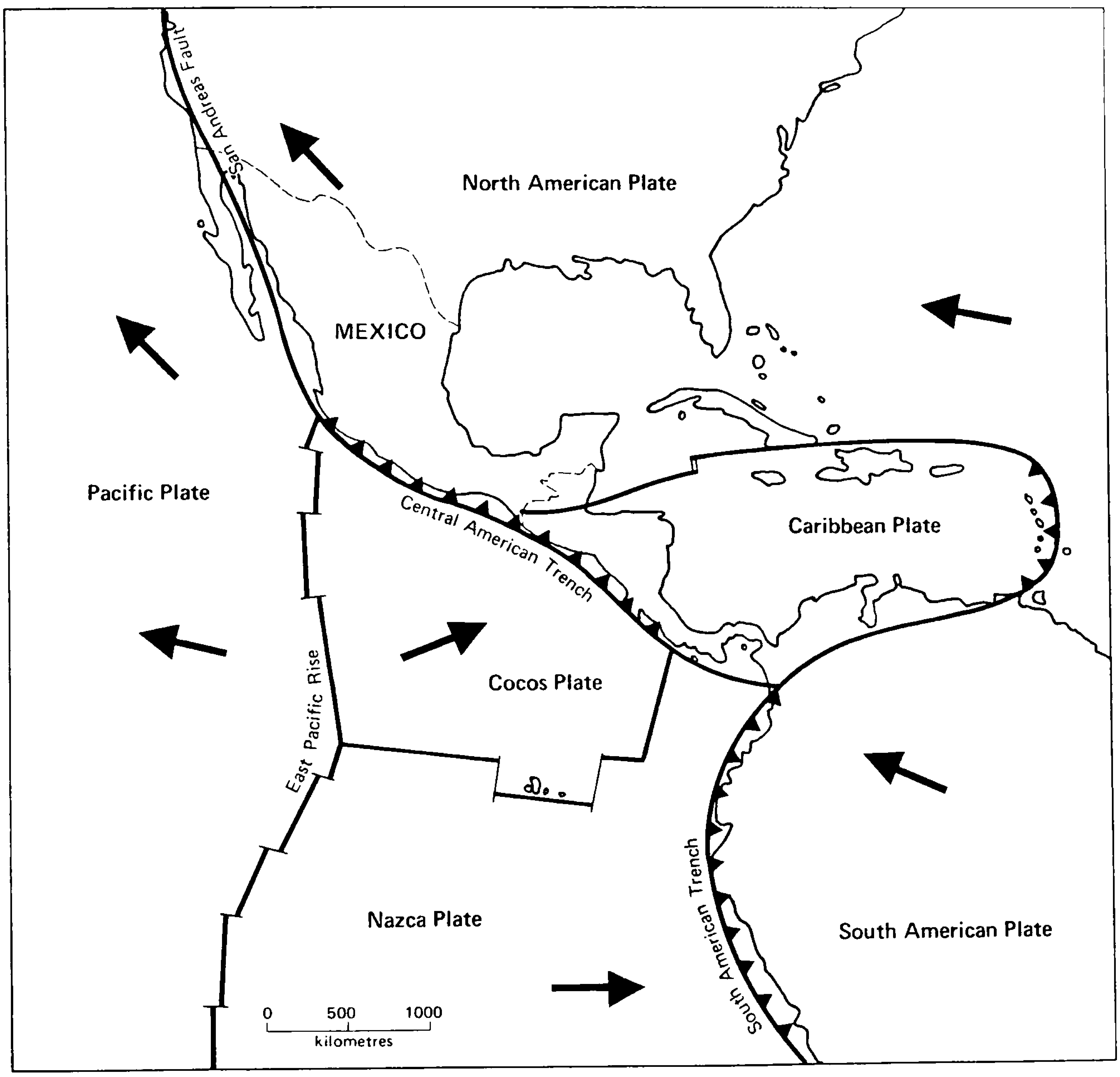
PART ONE. BACKGROUND TO THE 1985 EARTHQUAKE

2.2 MEXICO - REGIONAL SETTING

Mexico has a population of about 81,900,000 (1987), and a surface

Figure 2.1

PLATE TECTONICS
CENTRAL AMERICAN REGION



After R.O.A. (1977, p.15)

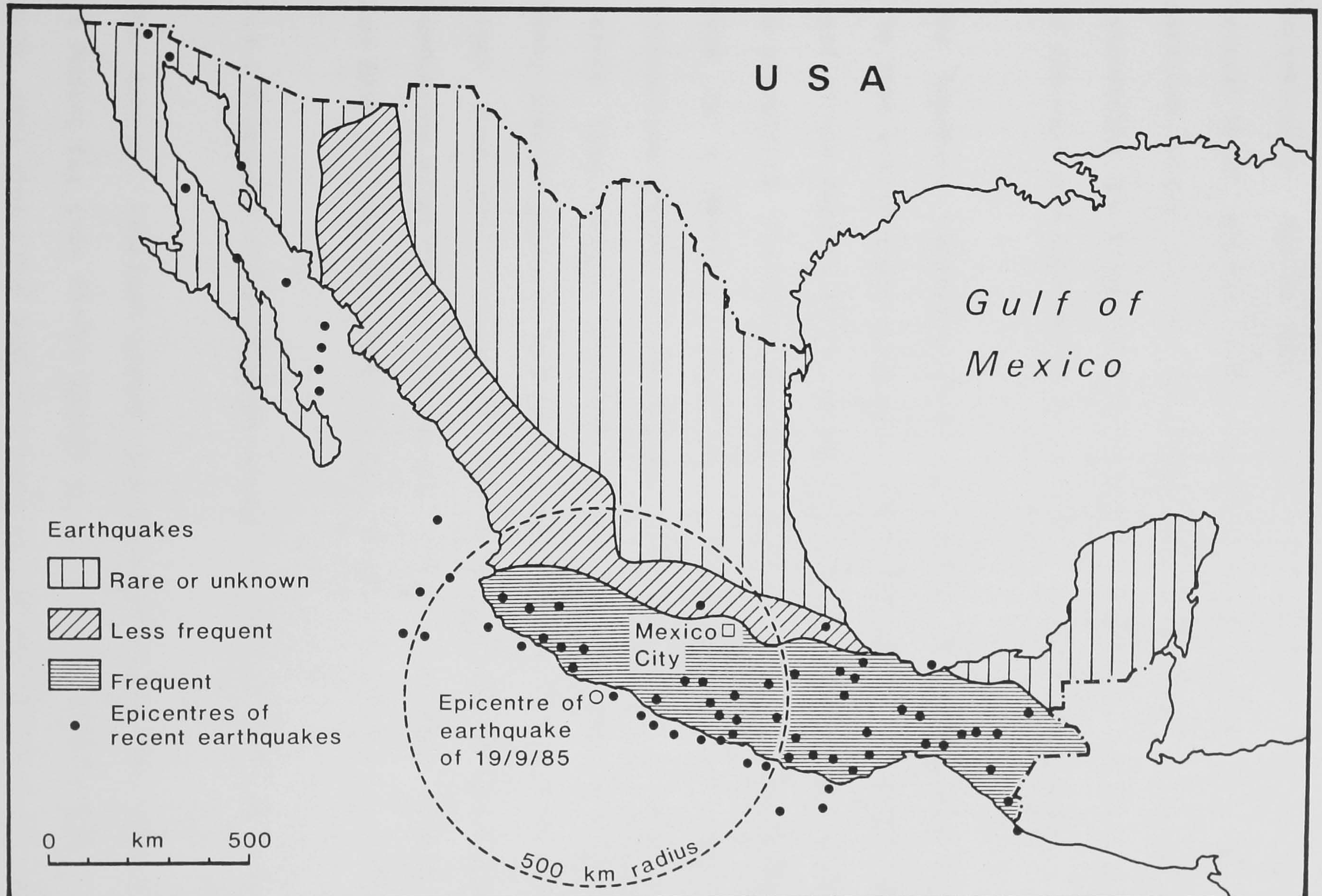
area of 761,600 square miles (approximately 2 million square kilometres). It lies between the Pacific Ocean and the Gulf of Mexico, and borders with the United States in the north, and Guatemala and Belize in the south.

The country typifies many of the problems that are to be encountered in the developing regions of the world (including the Middle East). In particular, Mexico has been unable to control its rapid rates of population growth (2.5% p.a.) and urbanisation. Nowhere are the unfortunate consequences of this more apparent than in the country's capital, Mexico City. This lies at the heart of the world's largest metropolitan area, which accommodates 18 million people (approximately one-fifth of the total population of Mexico) in an area that represents only 0.1% of the total land area of the country. Surrounded by shanty towns and slums, Mexico City symbolises all the dangers of uncontrolled urban growth. At present the population of the city is increasing by approximately 560,000 per year (U.N. statistics), and may reach a total of 30 million by the year 2000 (Fox and Carroll, 1984).

2.3 MEXICO AND EARTHQUAKES

Mexico has long been known to be a country of great seismic risk. It forms part of the Pacific rim known as the "Ring of Fire" because of its vigorous earthquake and volcanic activity. More than 90% of all the Earth's seismic energy is released along the tectonic zones that surround the Pacific plate (Munich Re., 1986). The majority of the Earth's active volcanoes are also located in this region.

Figure 2.2 The frequency of earthquakes in Mexico



After Cole (1985, Fig.1)

2.3.1 Tectonic setting

Tectonically, Mexico is strongly influenced by the interaction of several major plates (see Figure 2.1). Movement of the North American plate against the adjacent Pacific and Cocos plates, is responsible for the high incidence of volcanic and seismic activity in the west and south-west of the country (see Figure 2.2).

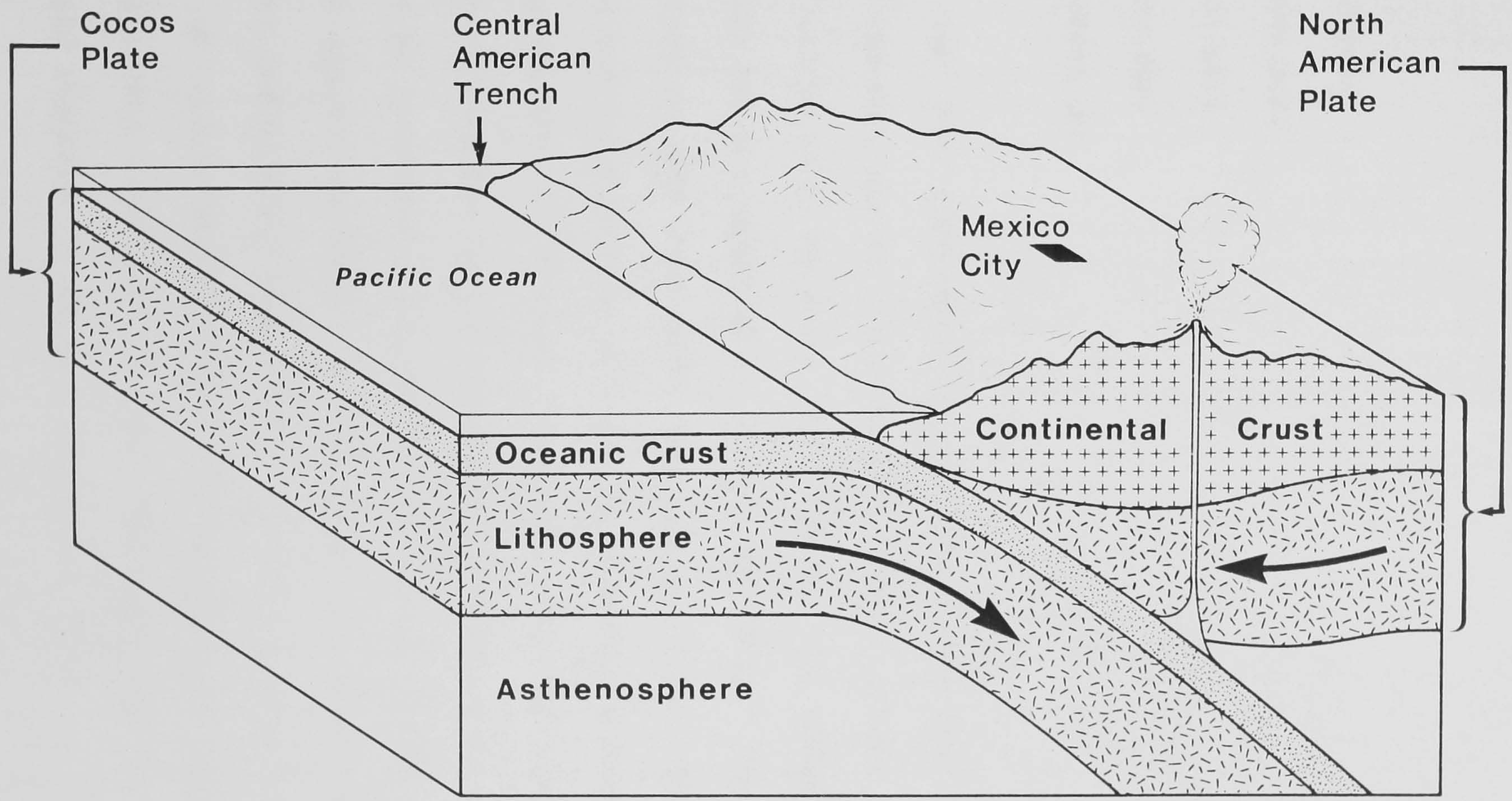
The boundary between the Cocos and North American plates is one of the most active plate margins in the world. The Cocos plate, forming part of the Pacific floor, is moving in a north-easterly direction. In opposition, the North American plate is carrying the Mexican land mass in a westerly direction. Figure 2.3 shows that the zone of interaction between the two plates is marked by a deep oceanic trench (the Central American trench), formed where the relatively heavy oceanic crust of the Cocos plate is thrusting beneath the light continental crust of the North American plate. The rate of subduction along the trench varies, but is typically between 50mm and 80mm per year (Mitchell <u>et al</u>., 1986).

2.3.2 Frequency of earthquakes along the Central American trench

The Central American trench runs parallel to the Pacific coastline of Mexico for over 1500km (Booth <u>et al</u>., 1986). Singh <u>et al</u>. (1981) have used historical and 20th century earthquake data, to conduct a detailed examination of the frequency of large earthquakes (Ms >=7.4) along this section of the trench. They conclude that, on average, the earthquakes have recurrence periods of between 32 and 56 years. There are, however, several notable "seismic gaps" along

Figure 2.3

A schematic diagram of the Subduction Zone off the west coast of Mexico



the trench that have not experienced any significant activity for well over 30 years. The gaps identified by Singh et al. (1981) are as follows (moving along the subduction zone from north-west to south-east):

a) the Jalisco gap;

b) the Michoacan gap;

c) the Guerrero gap;

d) the Ometepec gap;

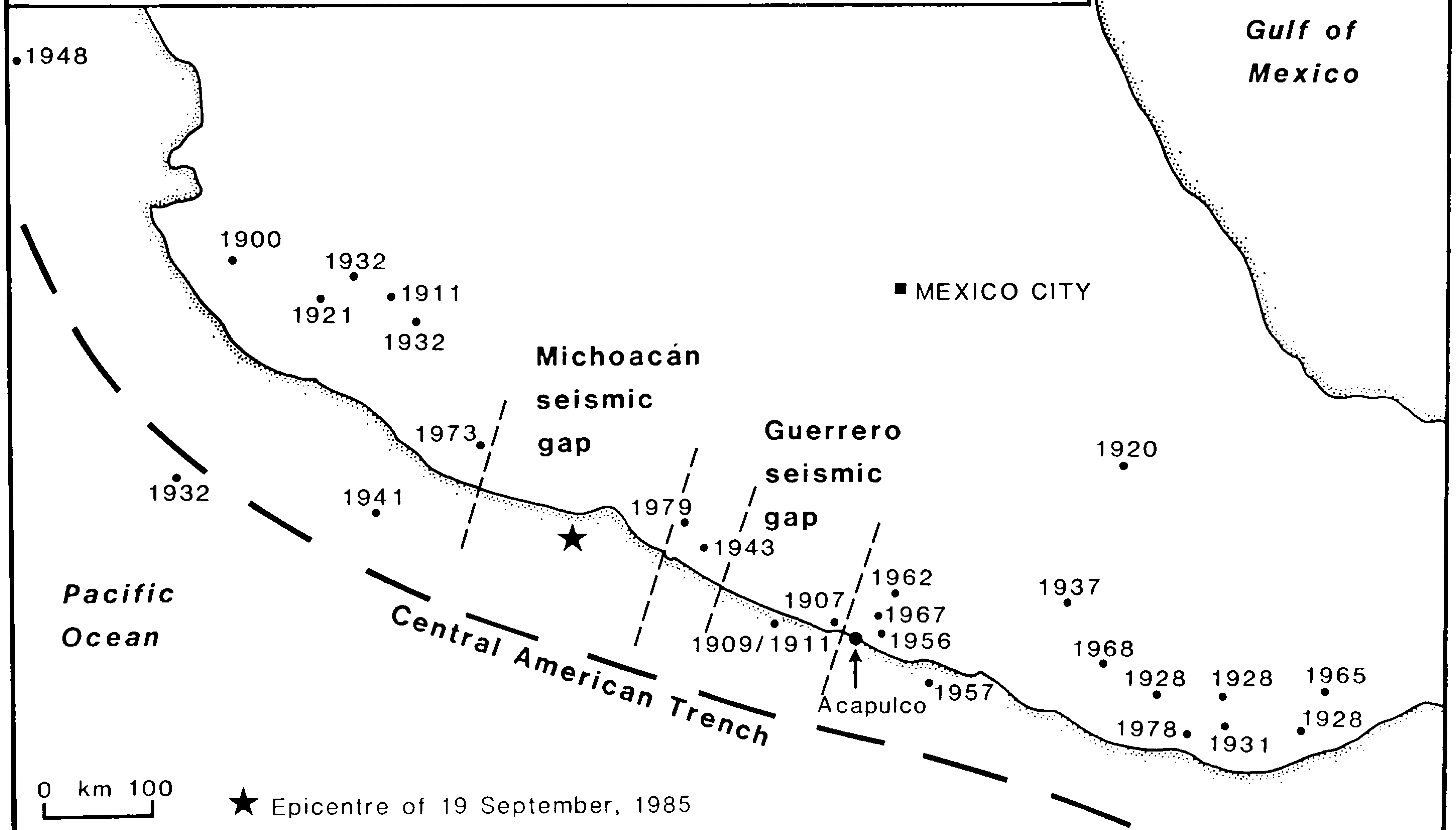
e) the Tehuantepec gap.

The Jalisco gap last experienced a large earthquake (Ms >=7.4) in 1932, and the Guerrero gap in 1911. The last major rupture in the Ometepec gap was in 1950. Up until 1985, however, the Michoaçan and Tehuantepec gaps had not experienced major earthquake events for much longer time periods than these. Singh et al. (1981) determined that both gaps had not ruptured during the present century, and probably not since the 18th century. They concluded that the absence of gap-filling earthquakes in the Michoacan and Tehuantepec regions, implied either an anomalously long earthquake return period (perhaps 200 years, as against the usual 30 to 70 years), or that subduction in the gaps was taking place aseismically (thereby preventing the accumulation of strain needed to generate earthquakes). The latter hypothesis was proved incorrect, for the Michoacan gap at least, when it suddenly ruptured on the 19th September, 1985.

Figure 2.4 shows the location of the Michoacan seismic gap. The epicentre of the 1985 Mexican earthquake clearly lies within the former "quiet zone", and proves conclusively that subduction along

Figure 2.4

Epicentres of twentieth century Mexican earthquakes with Richter magnitude (Ms) greater than 7.75



Source of data: Rinehart *et al.* (1982)

the Michoacan section of the trench occurs seismically (though with longer intervals between earthquakes than is normally the case). The 1985 earthquake and its aftershocks filled the gap completely (Mitchell et al., 1986). It is unlikely, therefore, that this section of the trench will rupture again within the foreseeable future.

However, this should not be taken to imply that the 1985 event has removed the immediate earthquake threat from Mexico. All four of the remaining seismic gaps have the potential to generate destructive earthquakes similar to that experienced in 1985. The Jalisco and Guerrero gaps in particular, are thought to be regions of high seismic potential (Singh et al., 1981). According to Massey et al. (1985), a large earthquake is likely to occur in the Guerrero gap before 1995.

The Guerrero gap is situated immediately to the south-east of the Michoacan gap (see Figure 2.4). Due to the fact that previous sequences of Mexican subduction earthquakes have tended to migrate along the subduction zone in a south-easterly direction (Mitchell et al., 1986), it is possible that the rupture in the Michoacan gap may have increased the likelihood of an earthquake in the Guerrero region. Munich Re. (1986) conclude that if an earthquake were to occur in the Guerrero gap today, it would probably have a magnitude of between 7.5 and 7.8. Such an event would be capable of causing another earthquake disaster in Mexico. It might even prove to be more destructive than the 1985 event, because of its greater proximity to Acapulco, and also to Mexico City.

2.4 THE 1985 MEXICAN EARTHQUAKE

The 1985 Mexican earthquake was the most destructive to affect the country this century. The earthquake (and its aftershocks) are estimated to have killed at least 10,000 people, injured 50,000, and made approximately 250,000 homeless. In addition, the earthquake caused roughly US$ 4,000 million worth of damage (Munich Re., 1986).

2.4.1 Seismology of the earthquake

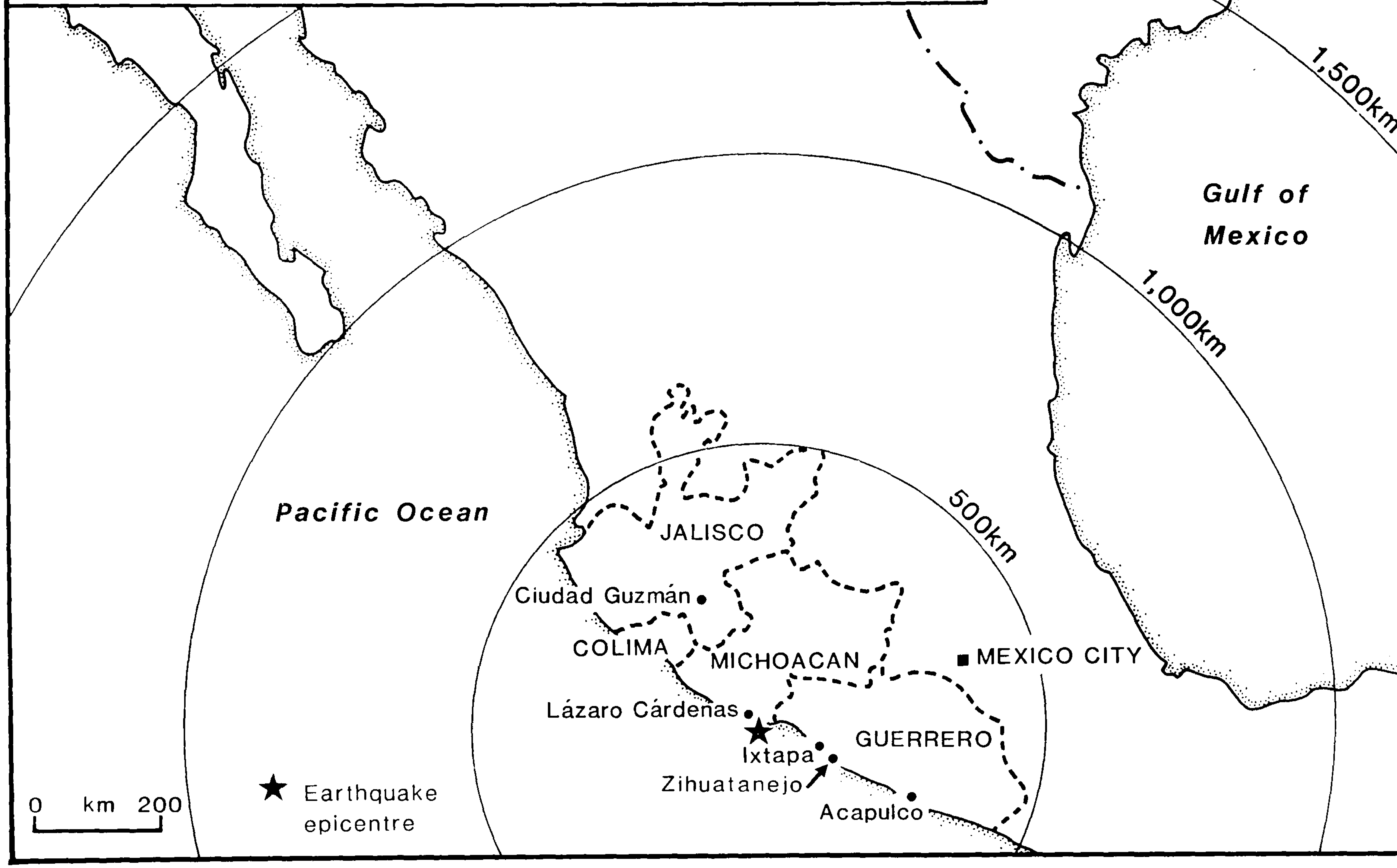
The main shock occurred at 13:17:47.6 GMT (7:17:47.6 local time), on the morning of Friday the 19th September, 1985. It had a magnitude (Ms) of 8.1 (Booth et al., 1986). A major aftershock (Ms 7.5) occurred on the 20th September, at 19.38 local time. The hypocentre of the main shock was at a depth of approximately 18km (Munich Re., 1986). The aftershock was also of shallow focal depth.

The epicentre of the major earthquake was at 18.1N, 102.3W (Hahn, 1986). From this, a rupture propagated in a north-westerly direction to about 103.5W (Mitchell et al., 1986). A short segment also ruptured to the southeast of the epicentre. The total length of the rupture was approximately 170km, and its width (normal to the coast) was 70km (Rosenblueth and Meli, 1986). The epicentre of the aftershock was located to the south-east of the major event, at 17.3N, 102W. The rupture was about 50km long (Mitchell et al., 1986).

Detailed measurements now available indicate that the rupturing process of the major earthquake was quite a complex one. The rupture

Figure 2.5

Areas affected by the 1985 Mexican earthquake



took place as two distinct breaks, separated by a time-lapse of 26 seconds (Munich Re., 1986). It was largely as a result of this that the earthquake was one of exceptionally long duration. Ground shaking in some coastal areas lasted over 5 minutes (Booth et al., 1986), and in parts of Mexico City lasted up to 3 minutes.

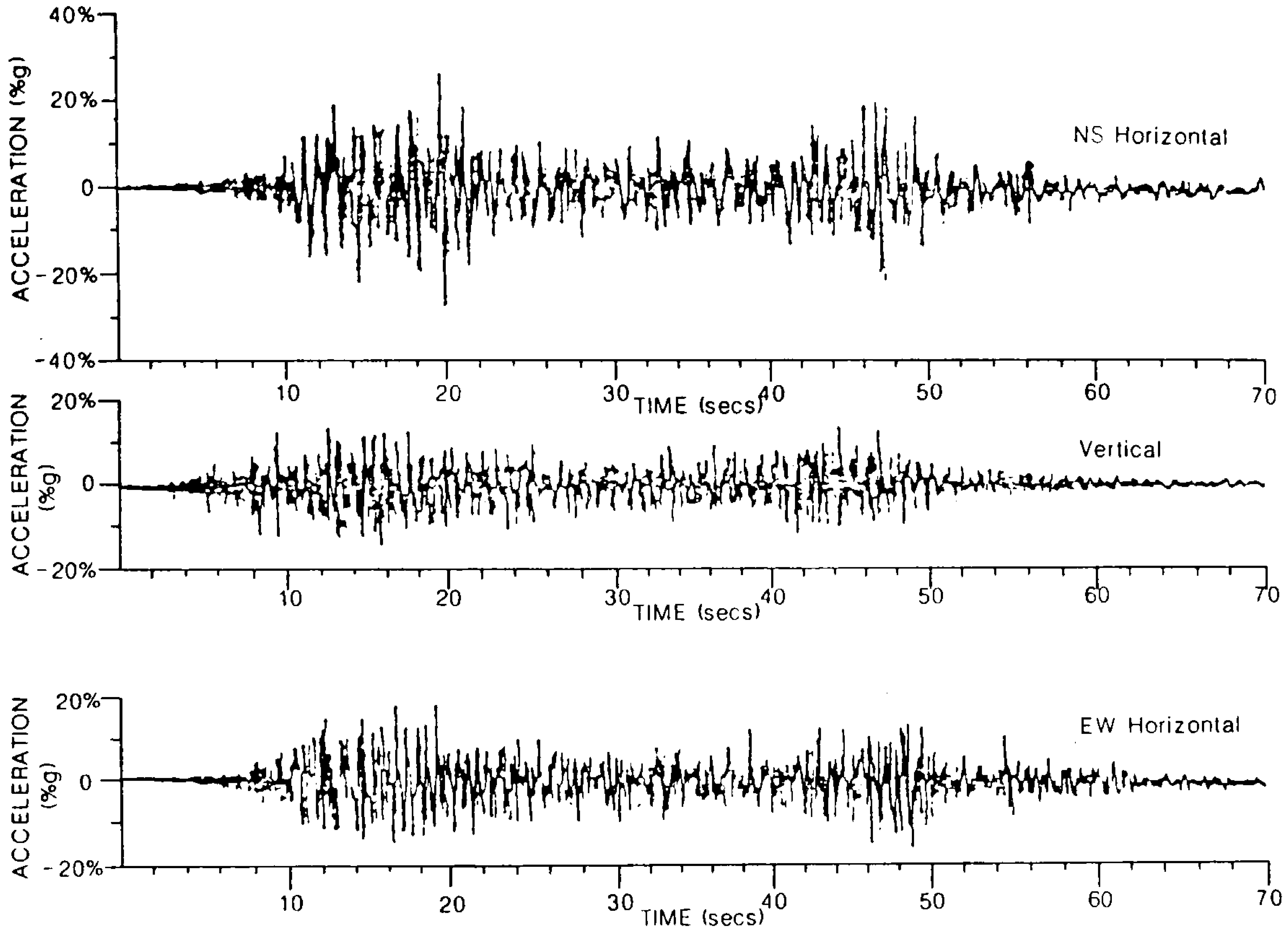
2.4.2 Ground motion in the epicentral region of the earthquake

Figure 2.5 shows that the epicentre of the Ms 8.1 earthquake was located just off the Pacific coastline of Mexico, near to the delta of the River Balsas (which lies along the state boundary separating Michoacan and Guerrero). The nature of the ground motion experienced in the epicentral region of the earthquake is illustated by Figure 2.6. This shows traces recorded by an accelerograph at Zacatula, which stands on compacted clays of the Balsas delta. The peak horizontal and vertical ground accelerations at Zacatula were about 27%g and 15%g respectively (where g = the acceleration due to gravity).

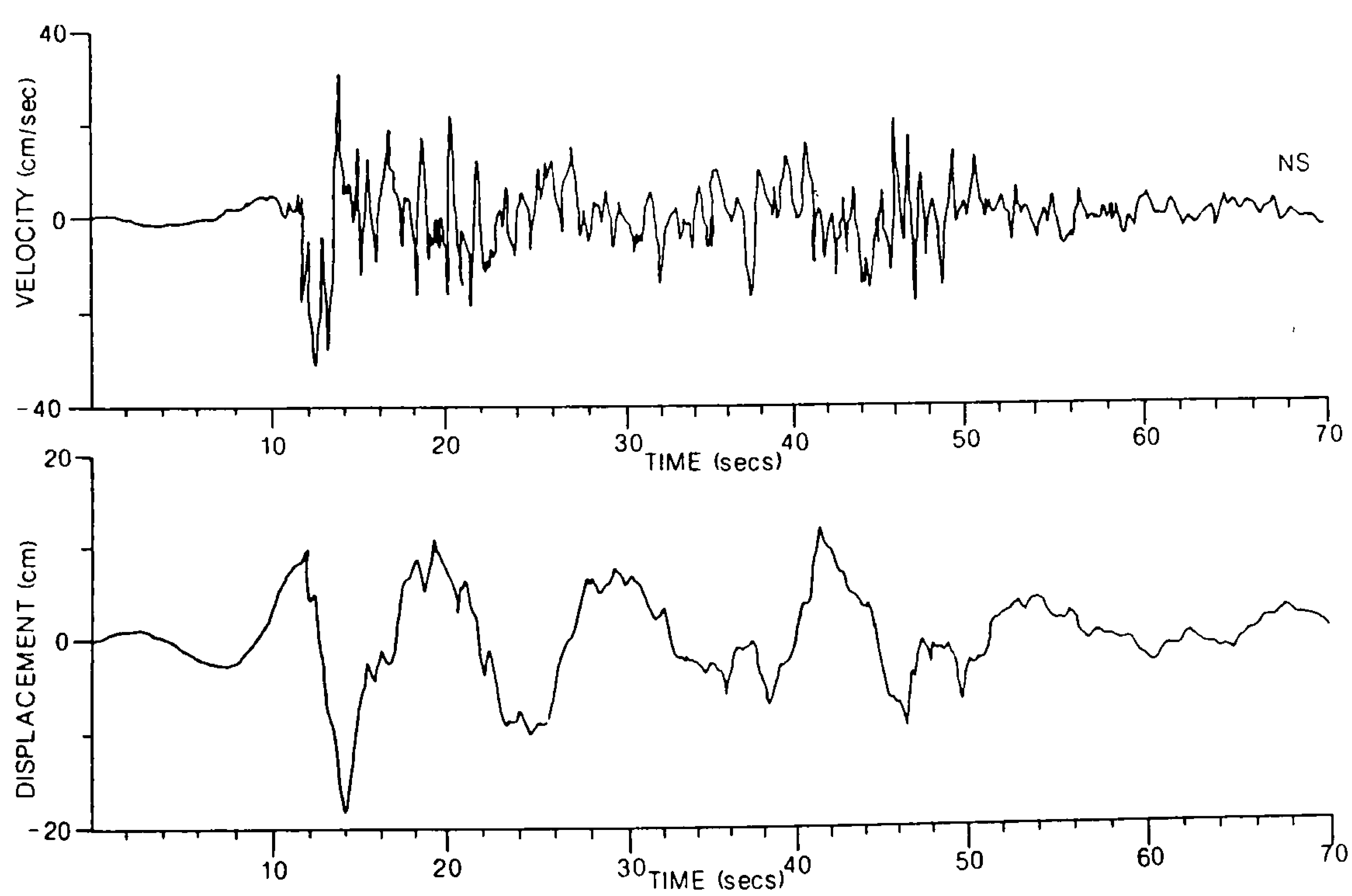
A number of rock-based accelerographs also recorded ground motion in the epicentral region of the earthquake. These showed peak accelerations of between 12%g and 17%g. Mitchell et al. (1986) have commented that these are very moderate values, considering the size of the earthquake. They are significantly smaller than the accelerations recorded on the clays of the Balsas delta.

Response spectra show that close to the earthquake epicentre, the ground motion contained both short period (high frequency) and long period (low frequency) vibrations. Periods of vibration ranged from

Figure 2.6 Strong motion records from Zacatula (near Lazaro Cardenas)



(a) Acceleration



(b) NS Horizontal - Velocity and Displacement

Source: Prince et al. (1985), as reproduced in Booth et al. (1986, Fig. 2.3) approximately 0.33 seconds to 10 seconds (Massey et al., 1985), but high frequency energy tended to predominate. At Zacatula, for example, the absolute spectrum for the N-S horizontal component of ground motion peaked at a period of 0.34 seconds (frequency of 3 Hertz).

Ground accelerations associated with the Ms 7.5 aftershock were less severe than those associated with the main earthquake event. Peak accelerations in excess of 10%g were recorded on rock, with a maximum acceleration of 20%g (Massey et al., 1985).

2.4.3 The distribution of damage

The earthquake was felt over an area of approximately 800,000 square kilometres. Some indication of the size of the event is provided by the fact that the shock waves rocked sky scrapers as far north as Houston, Texas, situated over 1500km from the epicentre (see Figure 2.5).

Damage was restricted to 6 out of the 32 major civil divisions of Mexico (Cole, 1985). The coastal states of Jalisco, Colima, Guerrero and Michoacan were amongst those affected, though damage in these areas was relatively light considering their proximity to the epicentre (see Figure 2.5). This would seem partly to be due to the sparse populations of these states, but more importantly to the hard crystalline bedrock that underlies much of the coastal region. This served to transmit the earthquake shock waves without amplification. The controlling influence that surficial geology exerted on the severity of ground motion in the epicentral region, is evident from the acceleration data presented in the previous section.

Along the coast, towns such as Ixtapa and Zihuatanejo were amongst the worst affected. However, they experienced only moderate damage, despite being less than 90km from the earthquake epicentre (see Figure 2.5). The city of Acapulco, situated 270km from the epicentre, was hardly affected by the earthquake at all. Each of the above mentioned towns/cities stands, for the most part, on crystalline bedrock.

In complete contrast, parts of Mexico City were severely shaken and experienced very heavy loss, despite being more than 400km from the earthquake epicentre. The city has repeatedly shown itself to be vulnerable to earthquakes, because it is partly underlain by the water-saturated sediments of an old lake bed.

The overall pattern of damage distribution caused by the 1985 earthquake, is very similar to that experienced in previous subduction zone earthquakes in Mexico. Prior to the 1985 event, the most damaging earthquake to have affected Mexico this century was that which occurred on the 28th July, 1957 (Ms 7.7). Figure 2.4 shows that the epicentre of the 1957 event lay off the Pacific coastline, to the south-east of Acapulco. Despite this, only relatively light damage was experienced in the coastal region, with Mexico City once again proving to be the worst affected area (Duke and Leeds, 1959).

2.4.4 Effects of the 1985 earthquake in the coastal states

In Jalisco state, as many as 150 people were killed by the earthquake (newspaper report). The worst affected town was Ciudad Guzman (population 60,000), where 26 people died, 700 to 800 were injured, and 2,000 families were made homeless (Booth et al., 1986). 40% of the buildings in the town are of adobe construction, and of these approximately 75% were damaged by the earthquake (Massey et al., 1985). Engineered structures performed much better, and few were affected.

Most of the serious earthquake damage in Ciudad Guzman occurred on sloping ground above an alluvial plain. The maximum intensity of shaking (Modified Mercalli) observed in this area of poor subsoil was VIII (Mitchell et al., 1986).

Up to 35 people are estimated to have been killed in Michoacan State, and 347 injured (newspaper report). Most of the losses occurred in the small industrial town of Lazaro Cardenas (population 150,000), situated close to the earthquake epicentre (see Figure 2.5). Approximately 80% to 90% of the buildings in the town were damaged (Lomnitz and Castanos, 1985). Ten modern medium-rise hotels (5 to 8 storeys high) were heavily damaged and forced to close. A number of public buildings and a hospital were also affected. The intensity of shaking at Lazaro Cardenas was probably between VIII and IX (Mitchell et al., 1986).

Higher intensities of ground shaking (i.e. IX or X) were experienced on the delta of the Balsas river (situated along the boundary between Michoacan and Guerrero). These can probably be attributed to amplification of the earthquake shock waves by the soft sediments of the delta (see Section 2.4.2). Evidence for severe ground motion across the delta included buckled and ruptured rail tracks (Mitchell et al., 1986), and earthquake-triggered liquefaction and subsidence (Hahn, 1986). A large industrial centre situated at the mouth of the Balsas river was particularly badly affected by the earthquake. Hahn (1986) estimates that US$ 40 million worth of damage was caused. A hotel in the delta area (at Playa Azul) collapsed killing a number of people (Mitchell et al., 1986).

In Guerrero State, the resort towns of Zihuatanejo and Ixtapa were worst affected. At Ixtapa, 9 high-rise beach hotels (10 to 15 storeys high) experienced non-structural damage. At Zihuatanejo, several buildings collapsed and one person was killed (Mitchell et al., 1986). The intensity of shaking experienced at Zihuatanejo and Ixtapa was probably VII (Mitchell et al., 1986).

No severe damage or deaths were reported from Manzanillo or Acapulco, where the intensity of shaking was probably only VI (Mitchell et al., 1986).

2.4.4.1 Tsunami damage

The Ms 8.1 earthquake triggered a tsunami which was observed at various Mexican coastal resorts, and also along parts of the coast of El Salvador (newspaper report). It reached the Mexican coast (at Lazaro Cardenas) 25 minutes after the earthquake occurred, and was between 1.9 and 2.0 metres high (Lomnitz and Castanos, 1985; Hahn, 1986). The tsunami caused minor damage on the Balsas delta, where parts of the industrial centre were flooded and rail tracks were washed away (Hahn, 1986).

2.4.5 Effects of the 1985 earthquake in Mexico City

In quantitative terms, the capital was by far the most severely affected city in the country. The downtown part of the city experienced particularly heavy damage. Several days after the earthquake, the Institute of Engineering at the National Autonomous University of Mexico (UNAM), estimated that the area of the city with significant damage covered 65 square kilometres. Of this, approximately 23 square kilometres showed a high density of damage (UNAM, 1985). Most of the damage in Mexico City was restricted to buildings. Other civil engineering works were hardly affected, and the city's infrastructure seemed to survive the earthquake remarkably well.

2.4.5.1 Building damage

Munich Re. (1986) estimate that 7,400 buildings in Mexico City were damaged by the earthquake. Of these, 770 were total losses and 1,665 were severely damaged. Many residential buildings in the central part of the city were put out of use, and thousands of people made homeless. The residential complex of Tlatelolco, situated just to the north of the centre of the city (Zocalo Square) was particularly badly affected. The estate covers 150 hectares and consists predominantly of medium to high-rise structures. 24 out of the 130 buildings in Tlatelolco were rendered unsafe by the earthquake, leaving thousands of families homeless. Part of the 13 storey Nuevo Leon building collapsed killing most of its 1,000 inhabitants.

In addition to the modern housing found in Tlatelolco, a large number of houses of poorer quality were also badly affected. These had not been designed to withstand an earthquake (and many were in a state of disrepair), so that they simply fell apart. Damage of this type was particularly severe in Morelos District, to the north of the Centre.

To the south of the Centre, the majority of streets in Colonia Roma experienced damage. Several high-rise residential buildings collapsed in the Benito Juarez housing estate. At the National Medical Centre on Cuauhtemoc Avenue, 8 out of the 9 buildings in the complex were damaged. Adjacent to this, the General Hospital was also seriously damaged, and one wing collapsed killing most of the staff and patients.

Perhaps the greatest single tragedy was the collapse of the 12 storey Juarez Hospital, situated just to the south of the Zocalo. This was reduced to the height of a 3 storey building, and as many as 1,000 people were killed. It seems very ironic that at a time when they were most needed, all three of the major hospital complexes in the centre of Mexico City were out of use.

A large number of office buildings were damaged, most notable of which were the 14 and 21 storey Law Court buildings at Pino Suarez. South of Pino Suarez, several high-rise factories collapsed along San Antonio Abad, killing hundreds of workers.

School buildings were also badly affected, and many were destroyed or seriously damaged. It is estimated that in the weeks immediately following the earthquake, over 1 million school children in Mexico City were without a school to attend (Cole, 1985). Fortunately most schools were empty at the time of the earthquake. It is beyond doubt that had the event occurred one hour later, at a time when schools and office blocks would have been full of people, then the number of fatalities would have been very much higher.

2.4.5.2 Power systems

By activating protective relays (which shut down the network), the earthquake caused interruptions in the power supply to a large part of Mexico City. Fortunately it did not damage generation equipment. By the 20th September, 75% of the city was receiving electricity. By the 25th, power had been restored to all buildings except those that had been badly damaged (Cole, 1985).

2.4.5.3 Water systems

Approximately 1,600 water pipes in Mexico City burst during the earthquake. As a result of this, the water supplies to 3-5 million people (and the airport) were affected to some degree (Booth et al., 1986). The eastern and south-eastern districts of the city suffered most, due to the failure of both of the major pipelines that supply this area. People living in the affected areas were forced to rely upon emergency tank supplies provided by the Government.

Due to the complexity of the water supply system and lack of accurate maps showing pipeline positions, repair of some broken pipes proved to be extremely difficult. By December, 1985, there were still many communities without a proper mains supply of water.

2.4.5.4 Transport systems

There was no significant damage to roads and bridges in the city, though tension cracking and compression buckling of pavements did occur around many of the taller buildings. Several streets remained closed after the earthquake whilst demolition of damaged buildings was taking place. Most notable of these was San Antonio Abad, parts of which remained closed for several months.

Bridges and underpasses in the city performed remarkably well, and there were no recorded failures. The Metro system was seemingly unaffected and fully operational within 24 hours of the earthquake having occurred (Booth et al., 1986). However, access to some stations was prevented by damage at the surface.

Runways at Benito Juarez International Airport survived the earthquake intact, as did the airport buildings. Flights to and from the airport were resumed shortly after the earthquake.

2.4.5.5 Telecommunication systems

The earthquake damaged several of the main telephone exchange buildings in Mexico City. As a result, all external and a large percentage of internal telephone communication in the city was lost. By the 30th September, 90% of communication systems within the city had been restored. External communications were restored just over a week later (Booth et al., 1986).

Telex equipment was not affected by the earthquake, thus enabling international links to be maintained.

2.4.5.6 Gas supplies

It is fortunate that there is no underground gas mains supply in Mexico City, and that propane gas is stored in tanks that are filled by tanker delivery. Propane gas systems did not suffer significant damage, as a result of which the number of explosions and fires triggered by the earthquake was limited.

PART TWO. ANALYSIS OF THE 1985 EARTHQUAKE DAMAGE IN MEXICO CITY

2.5 AIMS OF THE ANALYSIS

Subsequent to the earthquake, seven weeks were spent in Mexico City carrying out a detailed analysis of the damage. The main objectives of the work were:

a) To define the nature and distribution of damage in the city on a building by building basis;

b) To identify (as precisely as possible) the factors responsible for controlling the distribution of damage, paying particular attention to the influence of subsoil properties;

c) To examine the vulnerability of the different types of construction found in the city, to the type of ground shaking experienced during the earthquake.

In addition to carrying out the damage survey, time was also spent meeting representatives of various insurance and reinsurance companies based in Mexico, in order to determine the effect that the earthquake had upon them. Discussions were also held with members of several Institutes at the National Autonomous University of Mexico (UNAM).

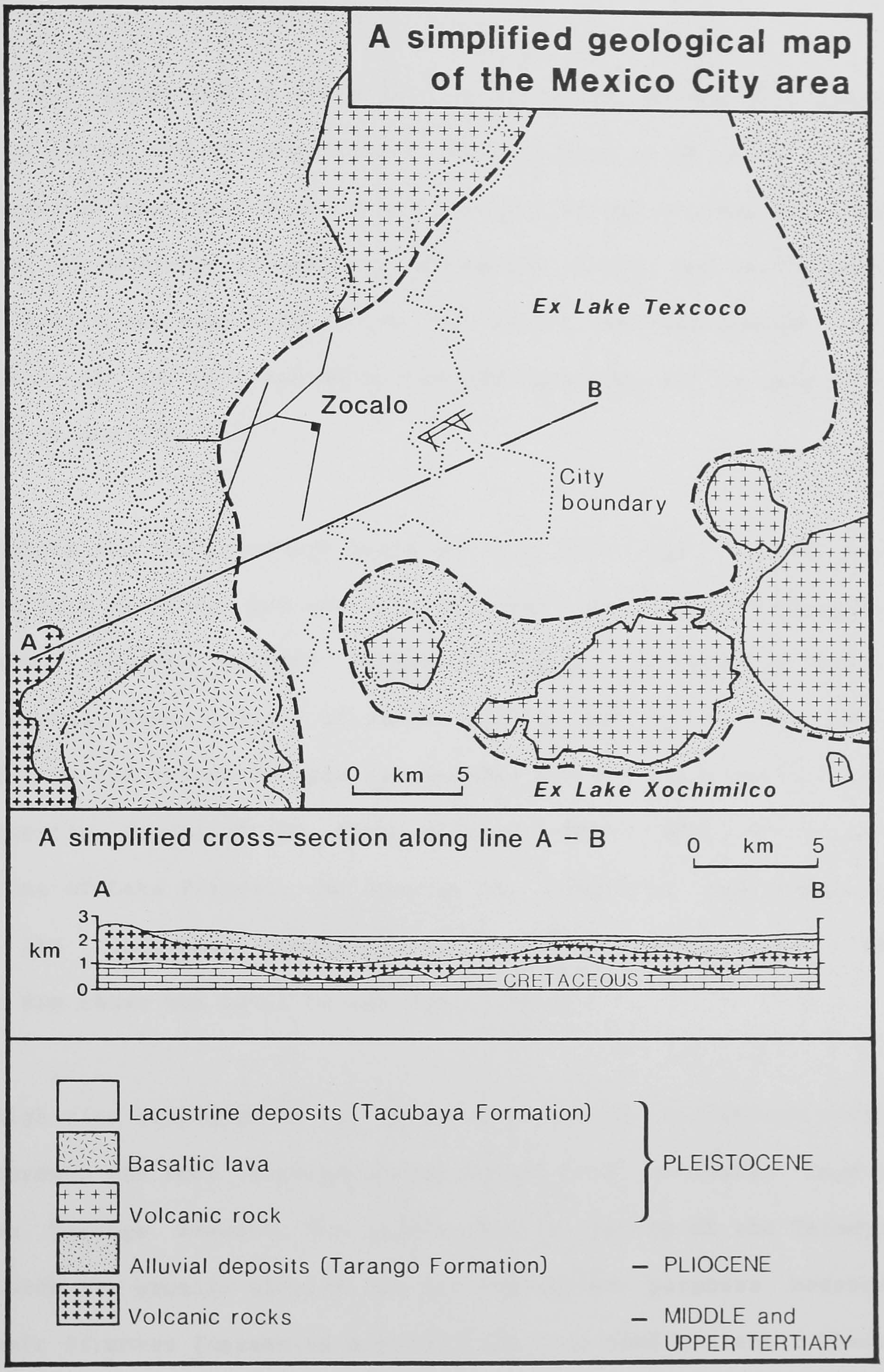
By way of introduction to the analysis, a brief account must first be given of the geological setting of Mexico City.

2.6 THE GEOLOGICAL SETTING OF MEXICO CITY

Marsal and Mazari (1959) and Marsal (1975), have provided excellent descriptions of the subsoil conditions in and around Mexico City. Much of the information presented in this section has been abstracted from their work.

Mexico City lies at an elevation of 2,250m above sea level, and is situated on the western side of the Valley of Mexico. This is a basin 65km by 80km in extent, that is ringed by volcanic mountains of up to 5,000m high. The city was founded by the Spaniards on the site of the great Aztec city of Tenochtitlan. At the time of the Spanish conquest in 1521, Tenochtitlan was situated on an island in the middle of a large lake (Texcoco), which was one of several covering the floor of the valley. Over the centuries this lake has

Figure 2.7


A simplified geological map of the Mexico City area
Ex Lake Texcoco
Zocalo
B
City boundary
A
0 km 5
Ex Lake Xochimilco
A simplified cross-section along line A – B
0 km 5
A
B
km
3
2
1
0
CRETACEOUS
Lacustrine deposits (Tacubaya Formation)
Basaltic lava
Volcanic rock
PLEISTOCENE
Alluvial deposits (Tarango Formation)
– PLIOCENE
Volcanic rocks
– MIDDLE and UPPER TERTIARY

gradually been reclaimed, so that today only a small remnant of it survives to the east of the city.

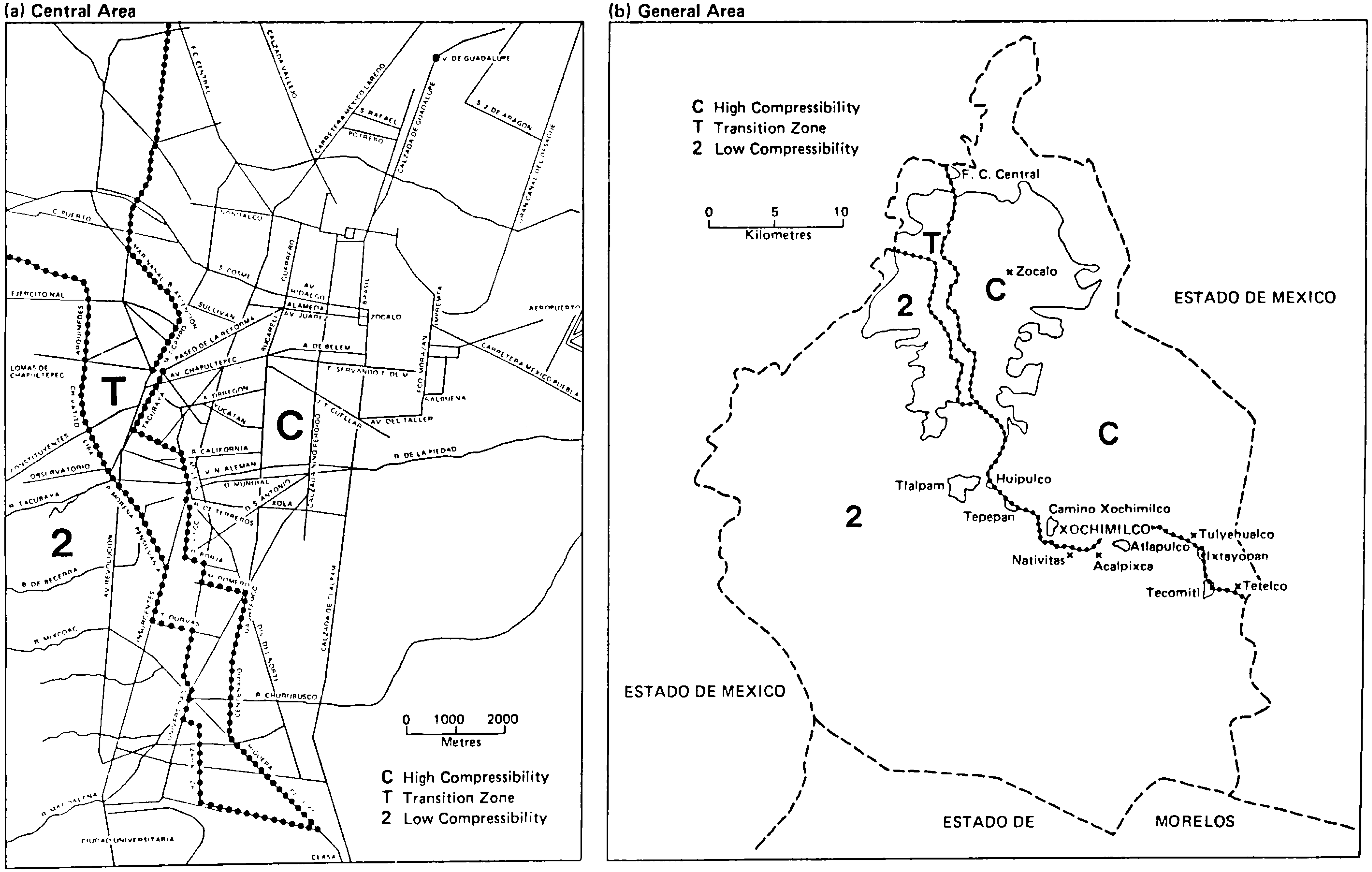
Figure 2.7 shows that a large part of modern-day Mexico City rests upon the former bed of Lake Texcoco. This is made up of thick layers of lacustrine clay belonging to the Tacubaya Formation. The clay is composed principally of montmorillonite and illite, and was derived from volcanic ash deposited in the lake during the Pleistocene. The thickness of the clay varies across the lake bed, but is generally between 7m and 37m.

The western and north-western parts of the city lie outside the ancient lake boundary, and are situated upon slightly older deposits belonging to the Tarango Formation (Upper Pliocene to Lower Pleistocene). These consist of sands, gravels and silts that were eroded from the volcanic cones surrounding the Valley of Mexico, and subsequently deposited to form alluvial fans. Above the former shoreline of Lake Texcoco, the Tarango has a depth of approximately 600m. Its topographic expression is in the form of hills that rise 30m to 60m above the level of the flat lake bed.

Many high-rise buildings on the lake bed have pile foundations which pass through the soft Tacubaya clays, to the more compacted layers of the Tarango beneath. Two layers near to the top of the Tarango succession are usually singled out for foundation purposes because of their firmness (caused by a relatively high sand content). These are often referred to as the "first hard layer" and "second hard layer". Near to the centre of the city, they are situated at depths below the surface of 31m and 41m respectively (Booth et al., 1986).

Figure 2.8 Earthquake tariff zones - Federal District

(a) Central Area (b) General Area



After R.O.A. (1977, p.33)

The southern part of the city stands upon basalt lava flows, the youngest of which date from about 2,400 years ago. The lava flows are often referred to as the "Pedregal".

2.6.1 Subsoil zonation of Mexico City

For engineering purposes, the area in and around Mexico City has been divided into three zones on the basis of subsoil properties. These are used by insurers and reinsurers as the earthquake tariff zones for the city (See Figure 2.8).

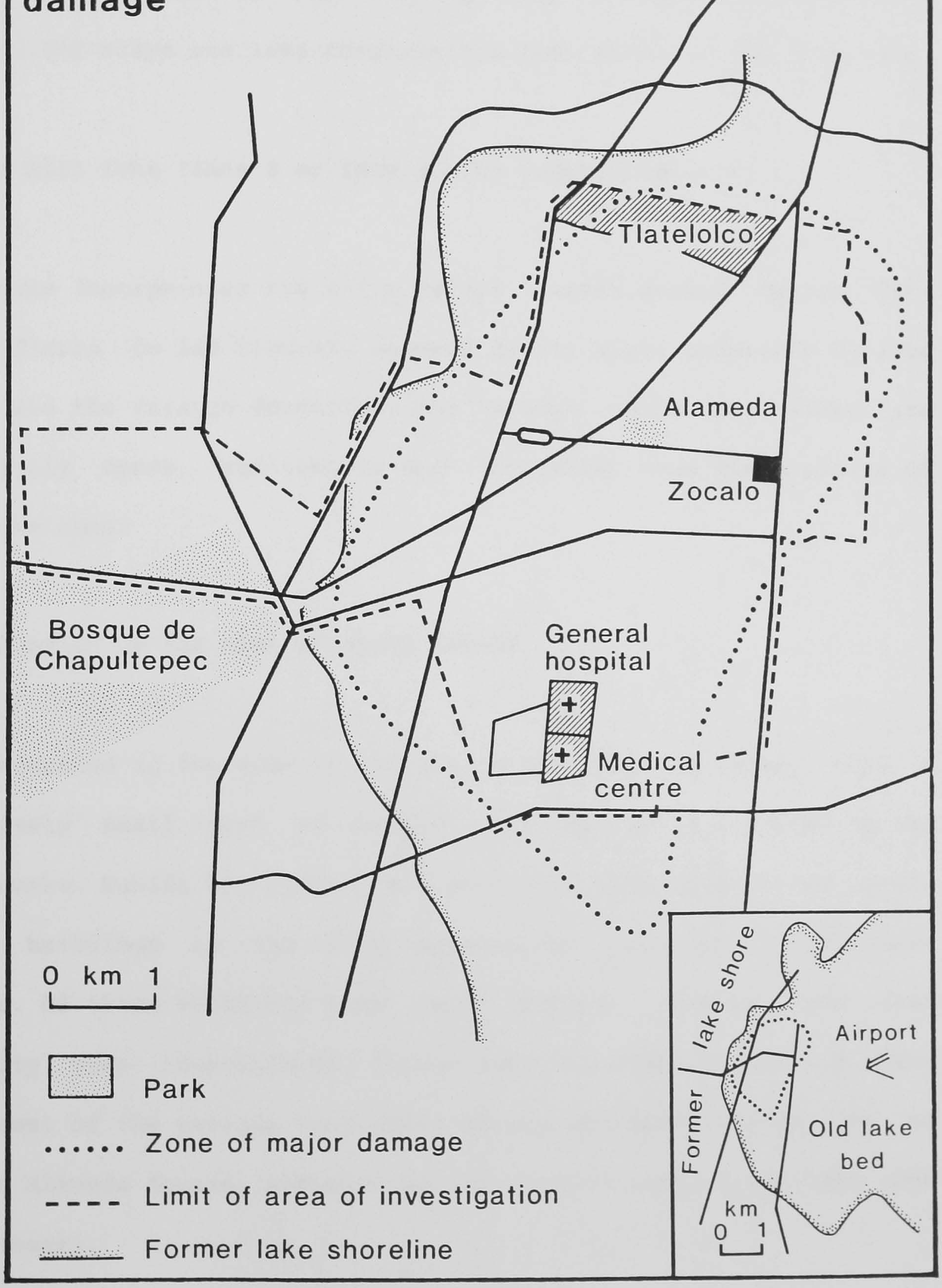
a) The Lake Zone (Zone C or Zone of High Compressibility)

This is the area previously occupied by Lake Texcoco. The Tacubaya clays of the lake zone have very high natural water contents of between 100% and 400%, and the water-table is commonly only 1m below the surface (Massey et al., 1985). The clays are highly compressible, so that small increments of pressure are capable of producing large settlements. The subsoil is so soft that many heavy buildings in the central part of the city have sunk into the clay, albeit only slightly in most cases.

Subsidence across parts of the lake zone has been artificially increased, due to excessive pumping of water out of the Tacubaya clays for industrial and domestic purposes. In the central part of the city, around the Zocalo and Alameda Square, settlement during the period 1891-1970 was between 5.5m and 8.5m (Booth et al., 1986).

Figure 2.9

Location map showing the area of investigation in relation to the zone of major earthquake damage



b) The Transition Zone (Zone T)

This lies between the lake and hill zones. It comprises areas which previously formed the shores of Lake Texcoco, so that the thickness and water content of the Tacubaya clay is greatly reduced. As a result, the clays are less compressible than those of the lake zone.

c) The Hill Zone (Zone 2 or Zone of Low Compressibility)

This zone incorporates the hilly volcanic areas around Mexico City (the Sierra de las Cruces), as well as the areas underlain by lava flows and the Tarango Formation. The Tarango sands and silts are relatively dense, and contain much less water than the deposits of the lake zone.

2.7 LOCATION OF THE AREA OF MAJOR DAMAGE

When compared to the size of the entire metropolitan area, only a relatively small part of Mexico City was badly affected by the earthquake. Munich Re. (1986) have estimated that only 1 in every 1,000 buildings in the city experienced significant earthquake damage. Of those buildings that were damaged, however, the vast majority were concentrated in one specific area: Figure 2.9 shows that most of the serious earthquake damage occurred within 2km to 4km of Alameda Square, situated in the western part of the lake zone (see inset).

2.8 THE FIELD ANALYSIS PROCEDURE

Within the area of major earthquake damage, two separate investigations were carried out:

a) Analysis of the distribution of damaged buildings;

b) Analysis of the vulnerability of different types of building to earthquake damage.

2.8.1 Damage distribution analysis

The area in which a detailed survey of earthquake damage was carried out is outlined on Figure 2.9. It clearly incorporates a large part of the zone of major damage. In addition, the limits of the investigation area were extended off the lake bed in a westerly direction, to include parts of the transition and hill zones. The purpose of this was to enable a comparison to be drawn between the severity of earthquake damage experienced in the three subsoil zones.

Within the area of investigation, the location of every building with visible external damage was recorded (the height and type of construction of each building was also noted). It was unfortunately not possible to inspect building interiors, and so the survey will have failed to detect some damaged structures.

Each building was assigned to a damage category according to the severity of observed damage. Five categories were used:

a) total collapse;

b) partial collapse (severe damage);

c) heavy damage;

d) moderate damage;

e) light damage.

The first two categories are self-explanatory. Buildings in the third category remained standing after the earthquake, but showed significant structural damage. Following the emergency revision of the building code (for Mexico City) on the 19th October 1985, many of the structures showing this class of damage had to be demolished. This was simply because it was uneconomical to repair them to conform to the new standards.

Buildings in the fourth category showed light structural damage, whereas those of the fifth category showed only minor damage that was largely superficial.

2.8.2 Building vulnerability analysis

In order to examine in detail the relative performances of different types of construction during the earthquake, it would be necessary to compare the damage statistics from the above survey, with an inventory of all the buildings in the investigation area at the time of the earthquake. Unfortunately such an inventory could not be obtained, and so a system of sampling by use of transects was devised.

Figure 2.10

Location of transects taken across the area of investigation

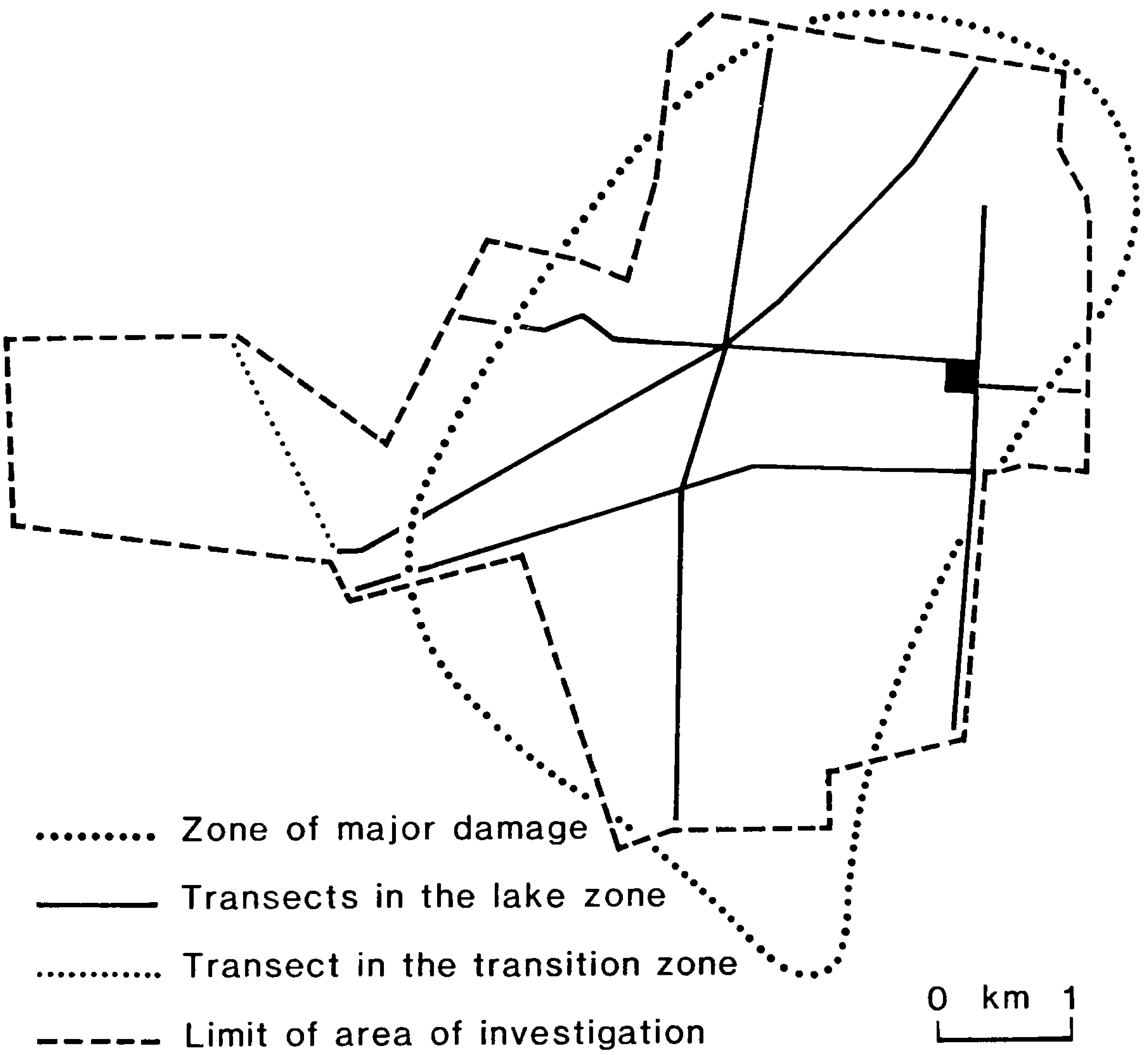
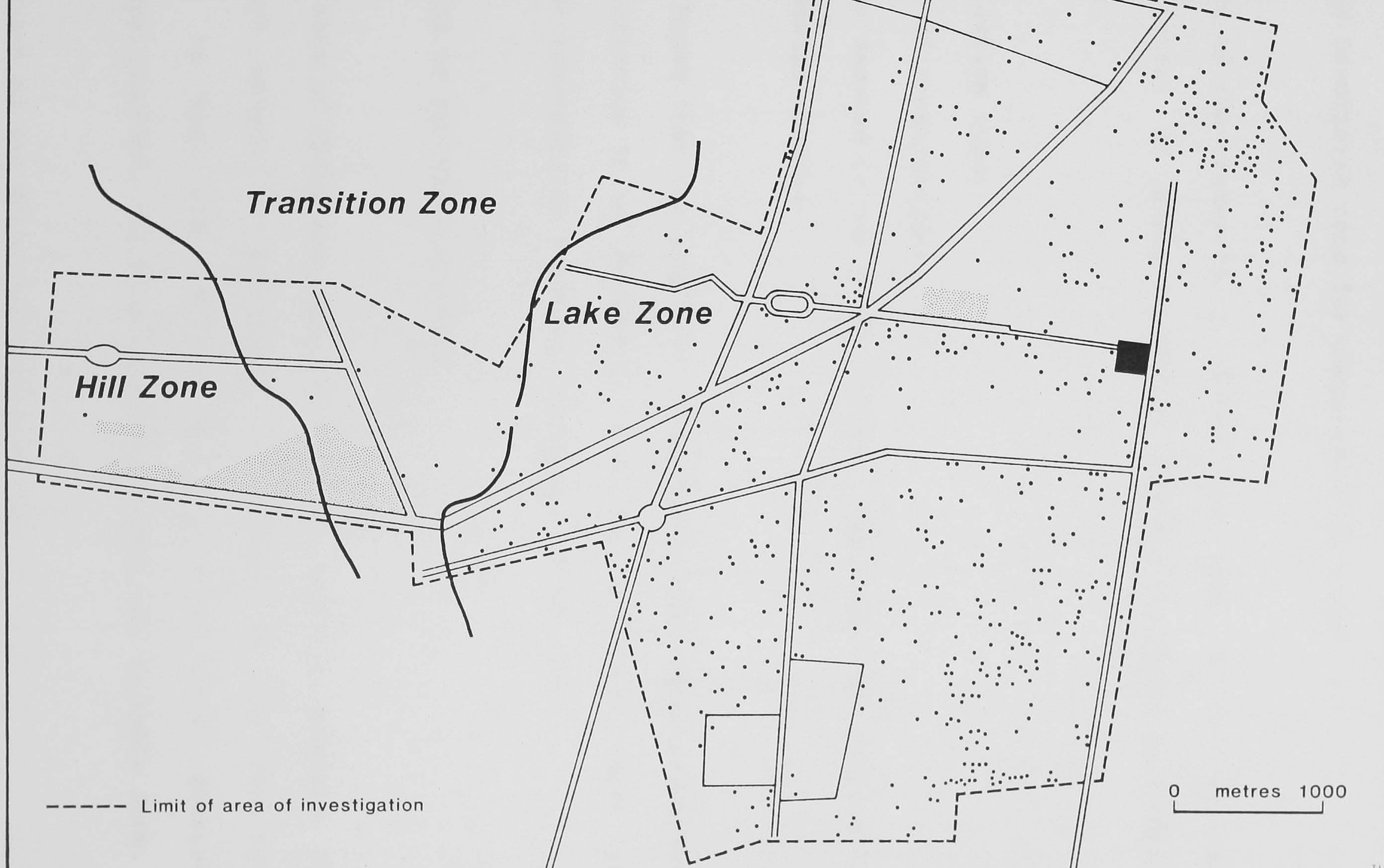


Figure 2.11

Location of buildings showing light superficial damage in relation to subsoil zonation



Five transects were taken across the lake bed area of major damage. These were positioned to provide as complete a sample coverage as possible (see Figure 2.10). In addition, one transect was taken across the transition zone for comparative purposes.

Along each of the transects, a survey was made of the external characteristics of every building, and the following information recorded:

a) Construction type;

b) Height of construction;

c) Whether damaged or not - no attempt was made to distinguish between damage classes.

It was hoped that the transects would enable meaningful percentage damage statistics to be determined for the different types and heights of construction found in the investigation area.

2.9 RESULTS OF THE FIELD ANALYSIS

The two sets of field analysis took over six weeks to complete. Due to the vast amount of information collected, it has not been possible to list all the raw data in this study. Wherever appropriate, however, the data have been summarised in table form.

2.9.1 Results of the distributional analysis

Of the five damage classes, the "light" class contained the largest number of buildings. It was also the one that was most evenly and

Figure 2.12

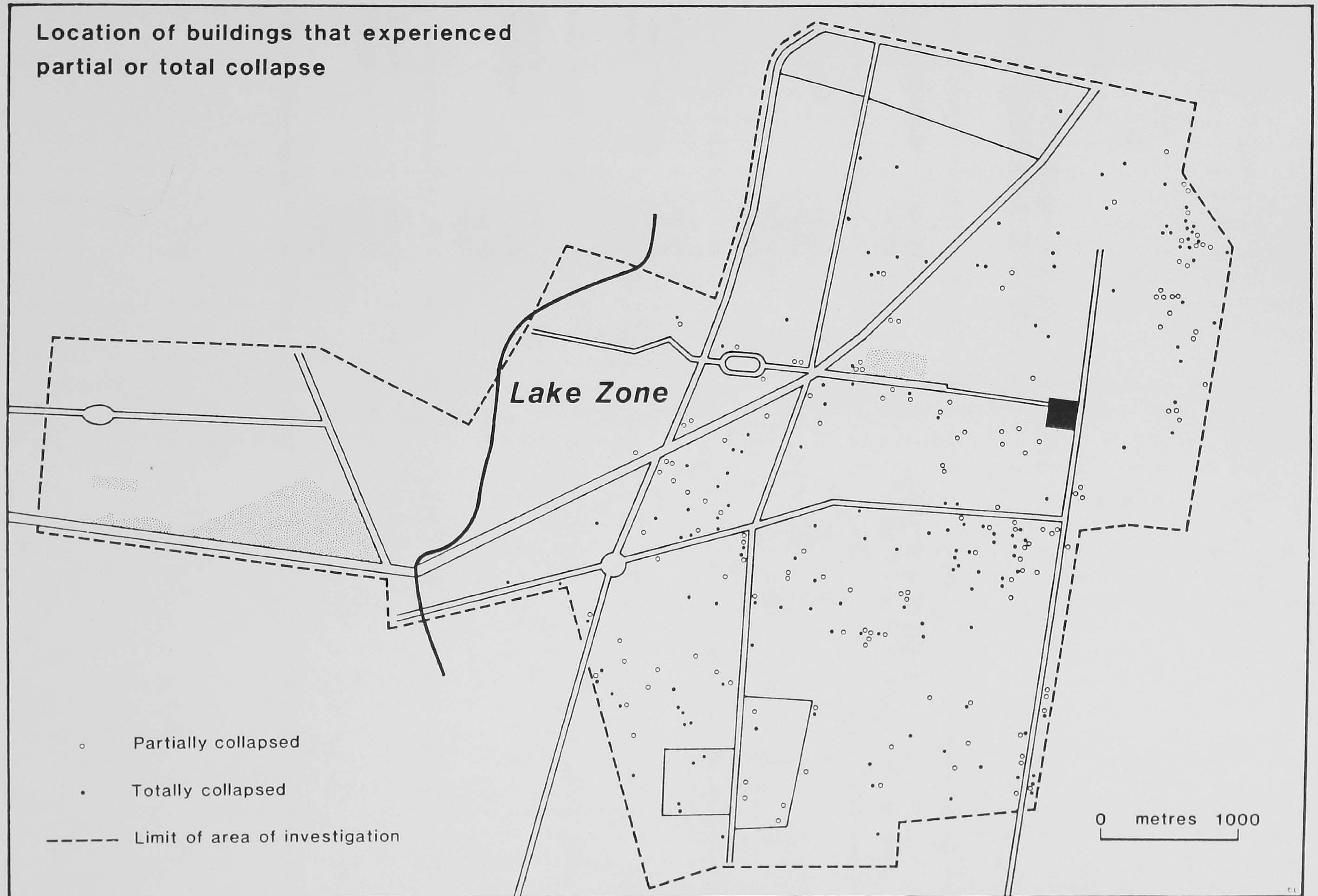

Location of buildings that experienced
partial or total collapse
Lake Zone
Partially collapsed
Totally collapsed
Limit of area of investigation
0 metres 1000

TABLE 2.1

Numbers of Damaged Buildings for Different Types and Heights of Construction

Construction Type	Damage Class	Number of Storeys <3	3-5	6-8	9-11	12-14	15-17	18-20	>20
Concrete Frame	Severe	7	15	29	16	5	5	-	-
	Heavy	3	35	50	50	31	10	2	-
	Moderate	13	42	77	41	24	14	5	2
	Light	20	76	84	36	11	8	5	7
Brick Load-bearing Wall	Severe	46	9	-					
	Heavy	62	21	1					
	Moderate	129	40	2					
	Light	219	80	2					
Stone Masonry	Severe	1	-						
	Heavy	4	-						
	Moderate	3	1						
	Light	16	5						
Steel Frame	Severe	3	-		-	-			
	Heavy	2	-		-	3			
	Moderate	-	1		1	-			
	Light	1	5		1	-			

widely spread across the area of investigation. Despite this, Figure 2.11 shows that the majority of the damaged buildings were confined to the lake zone. Only 11 (2%) of the 576 buildings with light damage were located in the transition and hill zones.

Buildings with categories of damage other than "light" were restricted entirely to the lake zone. With each successive damage class, the areal distribution of affected buildings was reduced slightly. Figure 2.12 shows the location of buildings that experienced failure (i.e. partial or total collapse).

The statistics relating to all the damaged buildings in the study area are summarised in Table 2.1. Data pertaining to collapsed buildings have been omitted, as it was frequently not possible to determine the former elevation of a totally collapsed structure. The table shows that three construction types predominate in Mexico City:

a) Reinforced concrete frame buildings, usually with exterior infill walls of brickwork or concrete slab. Street frontages are frequently of glass curtain walling;

b) Buildings with brick load-bearing walls. Adobe (mud brick) as well as fired brick has been used in the construction of some of the poorer quality buildings. In some buildings of this type, the bottom storey serves as a shop, and so has an open street frontage.

This type of construction is the one most commonly used in low-rise buildings. Standards of maintenance are often low;

TABLE 2.2

Damage Statistics Obtained from Five Transects
Across the Area of Major Damage

Construction Type		Number of Storeys							
		<3	3-5	6-8	9-11	12-14	15-17	18-20	>20
Concrete Frame	No. Observed	75	143	93	36	26	18	8	3
	No. Damaged	10	25	37	28	20	13	5	-
	% Damaged	13	17.5	40	78	77	72	62.5	-
Brick Load-Bearing Wall	No. Observed	214	108						
	No. Damaged	18	9						
	% Damaged	8	8						
Stone Masonry	No. Observed	21	28	1					
	No. Damaged	1	2	-					
	% Damaged	5	7	-					

c) Buildings of predominantly stone masonry construction. Many of the solidly built office blocks dating from the turn of the century are of this type of construction, as are most of the national monuments and old colonial buildings.

Few buildings belonging to categories (b) and (c) exceed 5 storeys in height (see Table 2.1). An additional minor category comprises buildings of steel frame construction, though these were seldom observed.

As regards the vulnerability of particular construction types to damage, it would obviously be unwise to try to draw conclusions from the data presented in Table 2.1. This is because they pertain only to damaged buildings, and do not give any indication whatsoever of numbers not affected by the earthquake.

2.9.2 Results of the vulnerability analysis

The results of the five damage transects in the lake zone have been combined and are presented in Table 2.2. For each construction type, percentage damage statistics for specific intervals of building height have been calculated. These are illustrated graphically in Figure 2.13. This figure clearly shows the influence of construction type and height, in controlling vulnerability to damage in the lake zone.

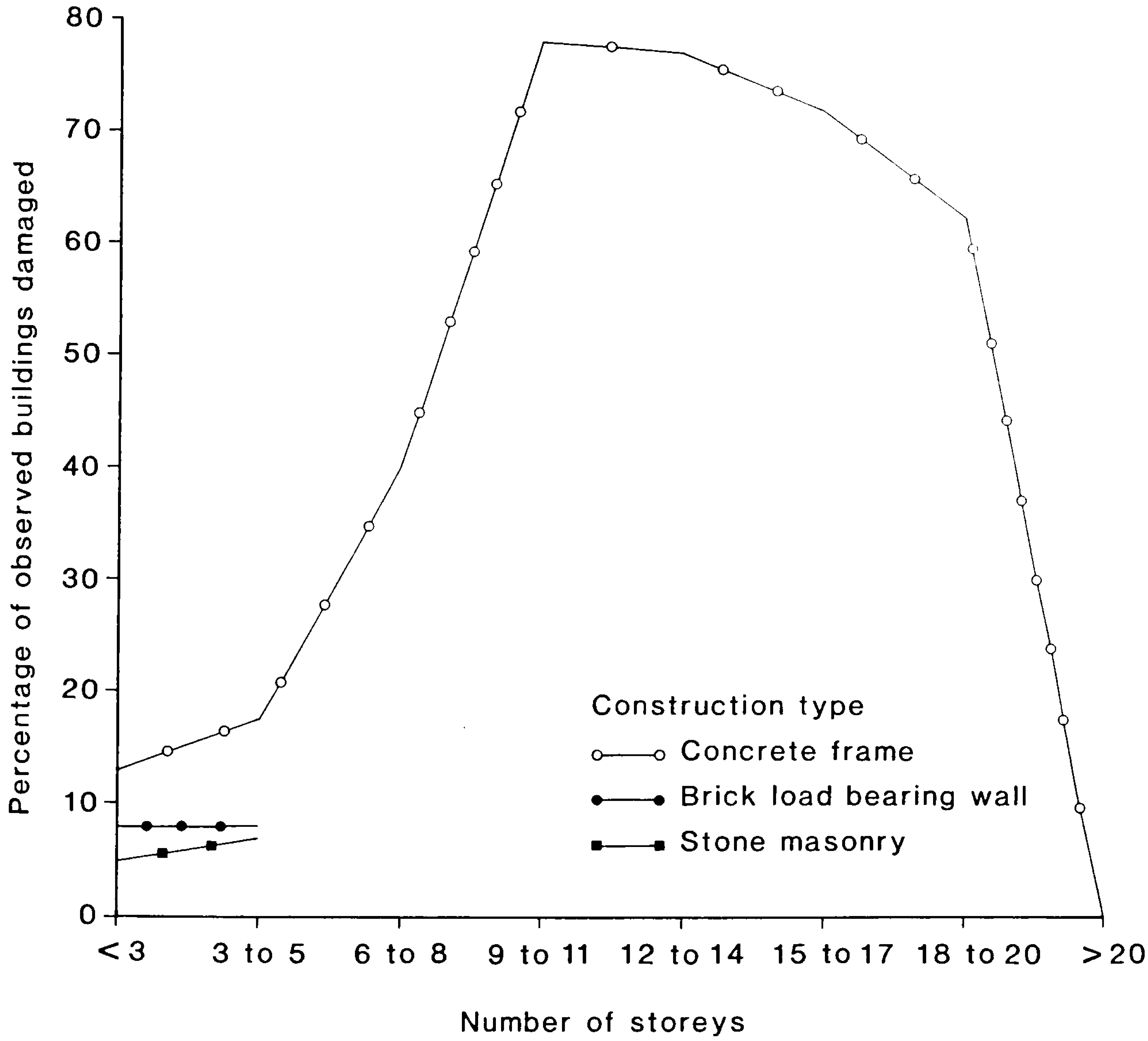
2.9.2.1 The influence of construction type

Figure 2.13 shows that in buildings of similar heights, there were

Figure 2.13

Percentages of buildings damaged according to type and height of construction

(Results of 5 transects across the zone of major damage)



quite significant differences in the incidence of damage observed in different construction types. In particular, for buildings between 1 and 5 storeys in height, concrete frame structures were most vulnerable to the ground shaking, with damages being successively reduced in buildings of brick load-bearing wall and stone masonry construction.

This would seem largely to be a reflection of the relative flexibilities of the three construction types in question. Many of the concrete buildings in Mexico City are very flexible in construction; they have flat waffle slabs and slender columns, but no real stiffening elements. In complete contrast, the thick-walled stone masonry buildings are very rigid, whereas the brick buildings are stiffer than the concrete frame structures yet slightly less rigid than the stone buildings. The low percentage of stone buildings damaged, attests to the more favourable response of the stiff buildings to the ground shaking.

2.9.2.2 The influence of height of construction

In addition to the effects of construction type, Figure 2.13 highlights the marked influence of building height in controlling vulnerability to damage during the earthquake. The damage curve for concrete frame structures shows that buildings in the height range of 6 to 20 storeys were particularly badly shaken, with the highest incidence of damage occurring in those between 9 and 11 storeys.

TABLE 2.3

Damage Statistics Obtained From a Transect Across the Transition Zone

Construction Type		Number of Storeys							
		<3	3-5	6-8	9-11	12-14	15-17	18-20	>20
Concrete Frame	No. Observed	14	19	19	3	6	4	3	1
	No. Damaged	-	-	-	1	1	-	-	-
	% Damaged	-	-	-	33	17	-	-	-
Brick Load-Bearing Wall	No. Observed	17	11						
	No. Damaged	-	-						
	% Damaged	-	-						
Stone Masonry	No. Observed	-	-						
	No. Damaged	-	-						
	% Damaged	-	-						

2.9.2.3 The transect in the transition zone

The results of the transect in the transition zone are listed in Table 2.3. This shows that, except for stone masonry buildings, all the types and heights of construction observed in the lake zone also occur in the transition zone. This eliminates the possibility that the marked contrast in the amounts of damage observed in the two zones (see Section 2.9.1), is due to large differences in the types of building found within them.

2.10 INTERPRETATIONS OF THE RESULTS

In order to interpret the results of the field analysis, it is necessary to consider the nature of the ground motion that was experienced in Mexico City during the earthquake.

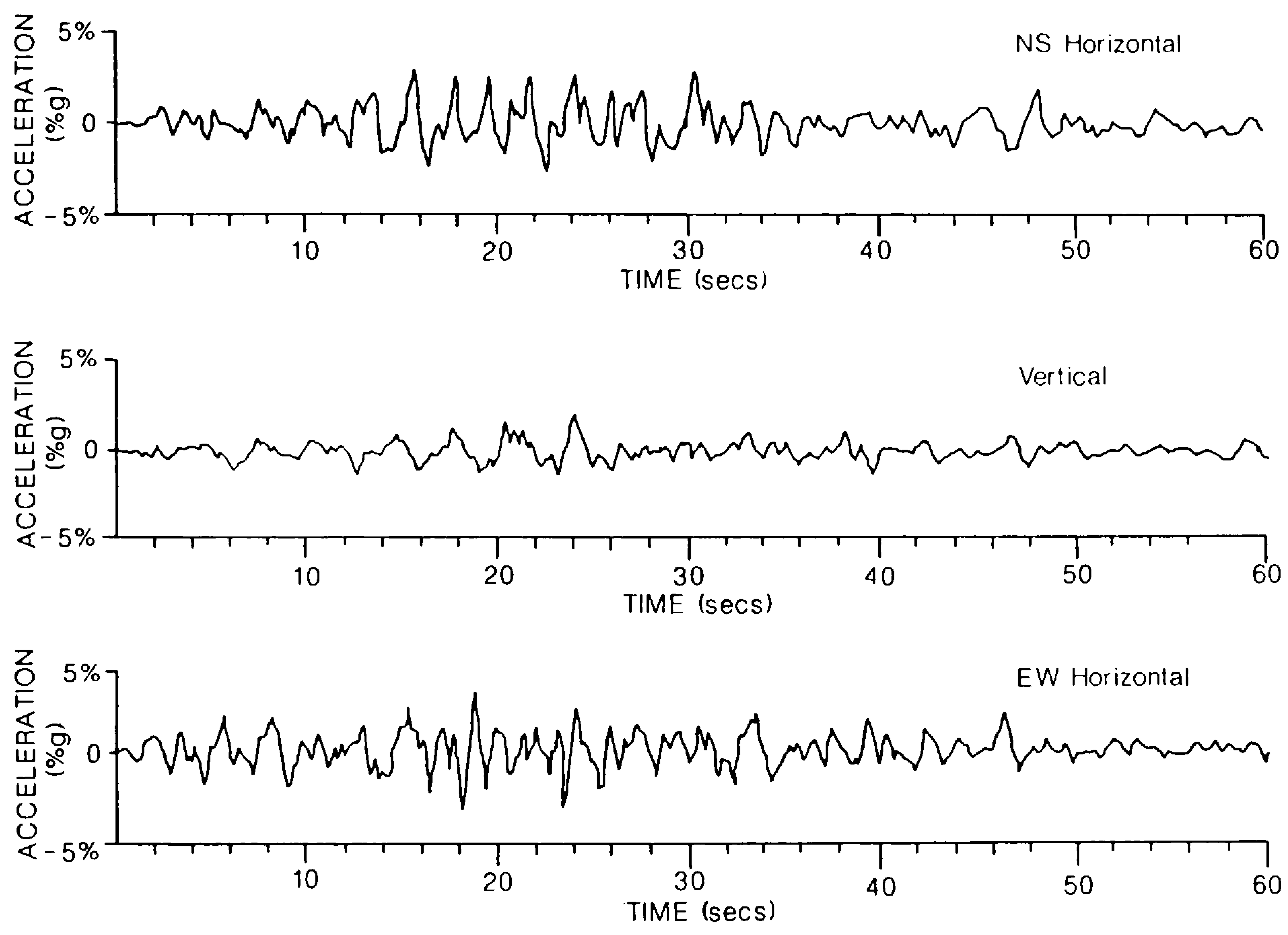
2.10.1 Ground motion in Mexico City

The ground motion experienced in Mexico City was very different from that experienced in the epicentral region of the earthquake. In Section 2.4.2, it was shown that at Zacatula (on the Balsas delta) close to the earthquake epicentre, a peak horizontal ground acceleration of 27%g was recorded. The peak accelerations recorded on solid rock were between 12%g and 17%g. The ground motion in the region contained both high and low frequency energy (with the former tending to predominate).

With increasing distance away from the earthquake epicentre, the amplitude of the earthquake shock waves gradually decreased.

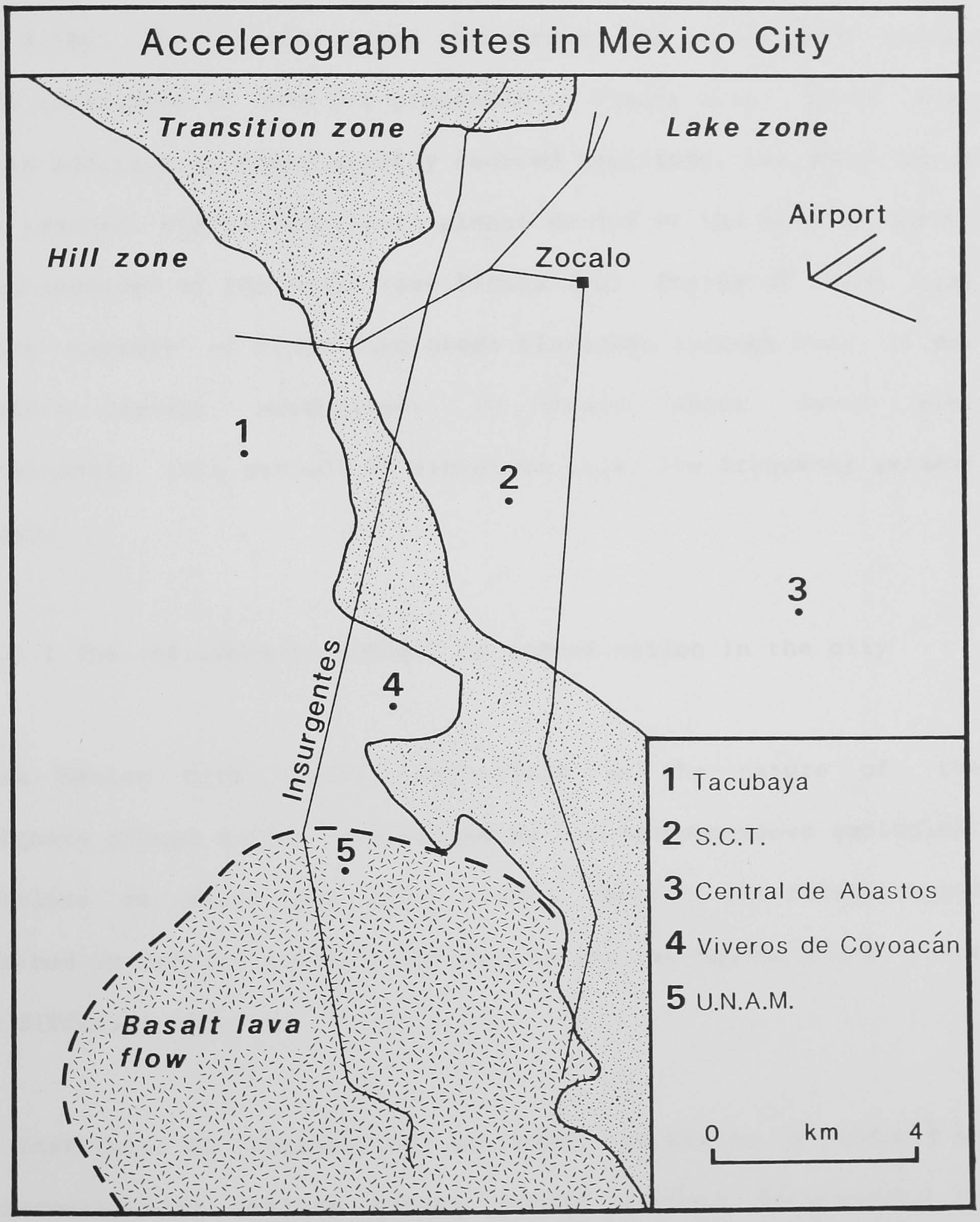
Figure 2.14

Strong motion records from a "free-field" instrument (situated on basalt) at UNAM, Mexico City



Source: Prince et al. (1985), as reproduced in Booth et al. (1986, Fig. 2.5)

Figure 2.15


Accelerograph sites in Mexico City
Transition zone
Lake zone
Airport
Hill zone
Zocalo
1
2
3
4
Insurgentes
5
Basalt lava flow
1 Tacubaya
2 S.C.T.
3 Central de Abastos
4 Viveros de Coyoacán
5 U.N.A.M.
0 km 4

Concomitant with this was a reduction in the severity of ground motion measured at the surface. By the time the shock waves reached Mexico City (over 400km from the epicentre), the "free-field" peak horizontal ground acceleration measured on solid rock (at UNAM) was only 3.5%g. The accelerograms recorded by the "free-field" strong motion instrument at UNAM are presented in Figure 2.14. These show that in addition to their greatly reduced amplitude, the shock waves that reached Mexico City were almost devoid of the high frequency energy recorded at the coast (see Figure 2.6). Energy of this type is not capable of travelling great distances through rock. It was therefore rapidly attenuated, to leave shock waves with predominantly long periods of vibration (i.e. low frequency seismic energy).

2.10.1.1 The influence of subsoil on ground motion in the city

Within Mexico City itself, variations in the nature of the earthquake ground motion were caused by the inhomogeneous geological conditions on which the city stands. Each of the subsoil types described in Section 2.6.1, responded to the earthquake shock waves in a different way.

The Institute of Engineering at UNAM, maintains a network of accelerographs to measure strong ground motions experienced in different parts of Mexico City during earthquakes. The location of these instruments is shown in Figure 2.15. Instrument 5 is the University accelerograph. As already mentioned, this is situated on solid rock (basalt) in the southern part of the city. In contrast, instruments 1 to 4 are situated on "soft-ground" in other parts of

TABLE 2.4

Summary of Peak Ground Motions Recorded at 'Free-Field' Sites in Mexico City During the Earthquake of September 19, 1985

VARIABLE	DIRECTION OF MOTION	INSTRUMENT SITE*				
		UNAM (5)	VIVEROS (4)	CENTRAL (3)	SCT (2)	TACUBAYA (1)
Acceleration (cm/sec^2 or $10^{-3}g$)	Longitudinal (N-S)	32	44	81	98	34
	Transverse (E-W)	35	42	95	168	33
	Vertical (V)	22	18	27	36	19
Velocity (cm/sec)	N-S	10	11	25	39	14
	E-W	9	12	38	61	10
	V	8	6	9	9	8
Ground Displacement (cm)	N-S	6	9	15	17	12
	E-W	8	7	19	21	9
	V	7	7	8	7	8

* See Figure 2.15

Source of data: Prince *et al.* (1985)

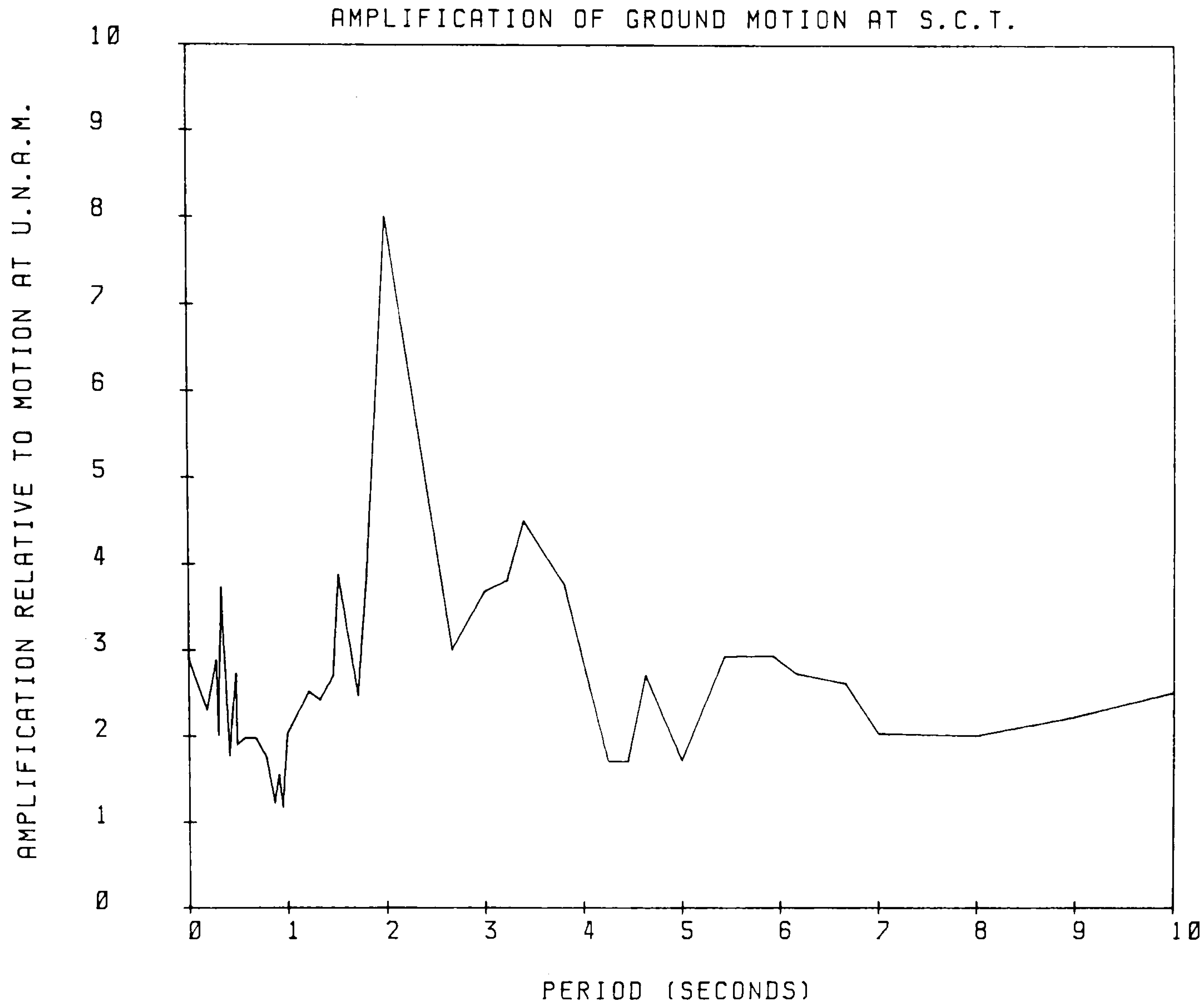
the metropolitan area. Instruments 2 and 3 stand on Tacubaya clay in the lake zone, whereas 1 and 4 are situated on Tarango deposits in the hill zone (for geological setting, see Figure 2.7).

Peaks of ground motion recorded at each of the accelerograph sites in Mexico City are listed in Table 2.4. This shows that peak horizontal ground accelerations varied very considerably between the different subsoil zones. Though not affected to such a degree, there were also significant differences in the peak vertical ground accelerations measured.

The peak horizontal ground acceleration recorded in the hill zone was approximately 4.5%g. This was slightly higher than the peak recorded at UNAM (3.5%g). In the lake zone, the peak was 17%g. Using data recorded at SCT (Site 2), Prince et al. (1985) have calculated that the direction of greatest motion on the lake bed was S60E, along which an acceleration of 20%g occurred; i.e. almost 6 times more severe than the peak acceleration on solid rock at UNAM (situated only 8km to the south-west). In addition to amplifying the earthquake shock waves in this way, the soft clays of the lake zone also served to prolong the duration of ground shaking. Strong motion at UNAM lasted approximately 1 minute (see Figure 2.14), whereas that at Central de Abastos (Site 3) lasted almost 5 minutes (Prince et al., 1985).

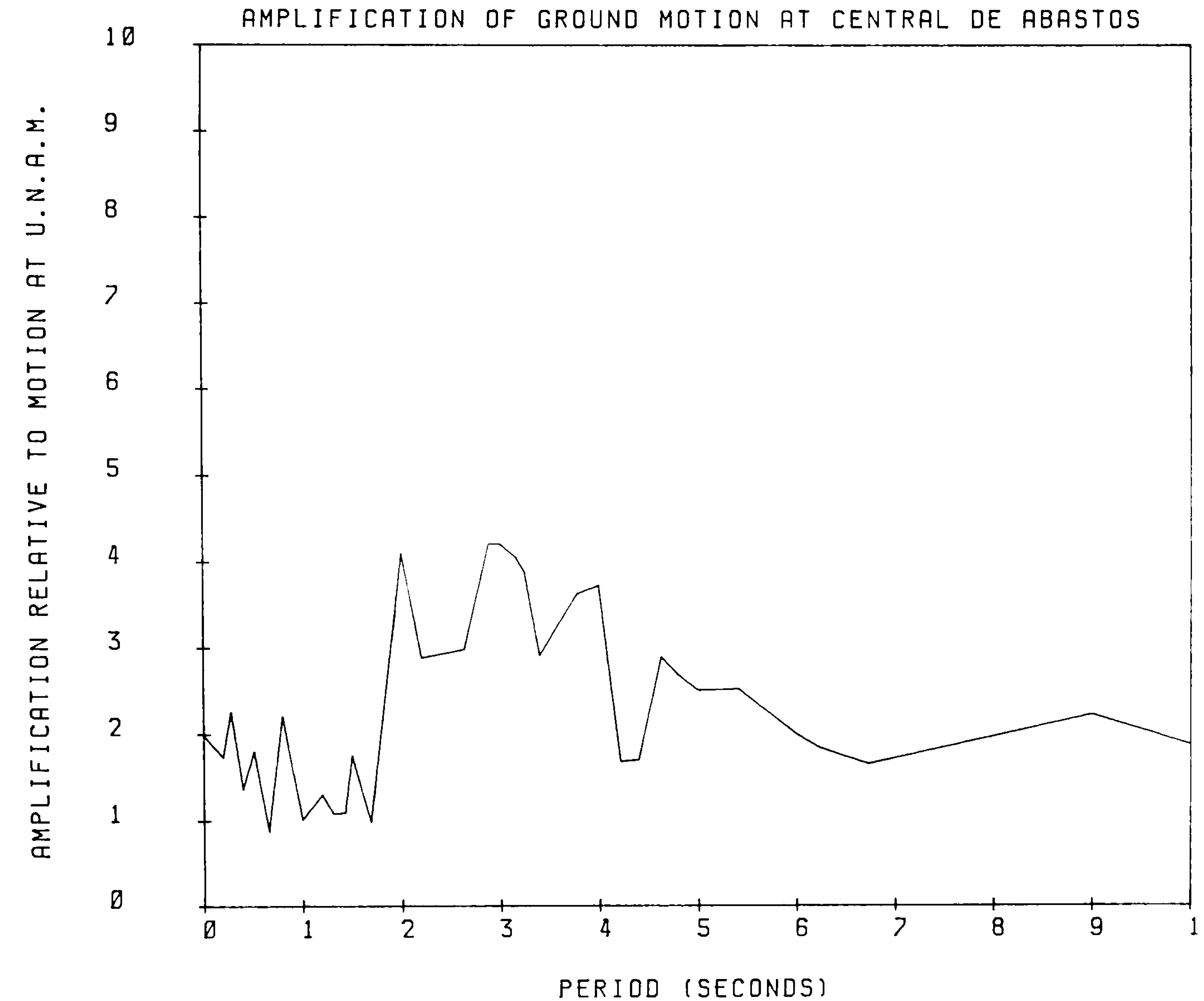
Figures 2.16 to 2.19 are spectral ratios that have been produced using data taken from Prince et al. (1985). They compare the acceleration spectrum recorded at each of the "soft-ground" sites in Mexico City, with that recorded on solid rock at UNAM. The figures

Figure 2.16



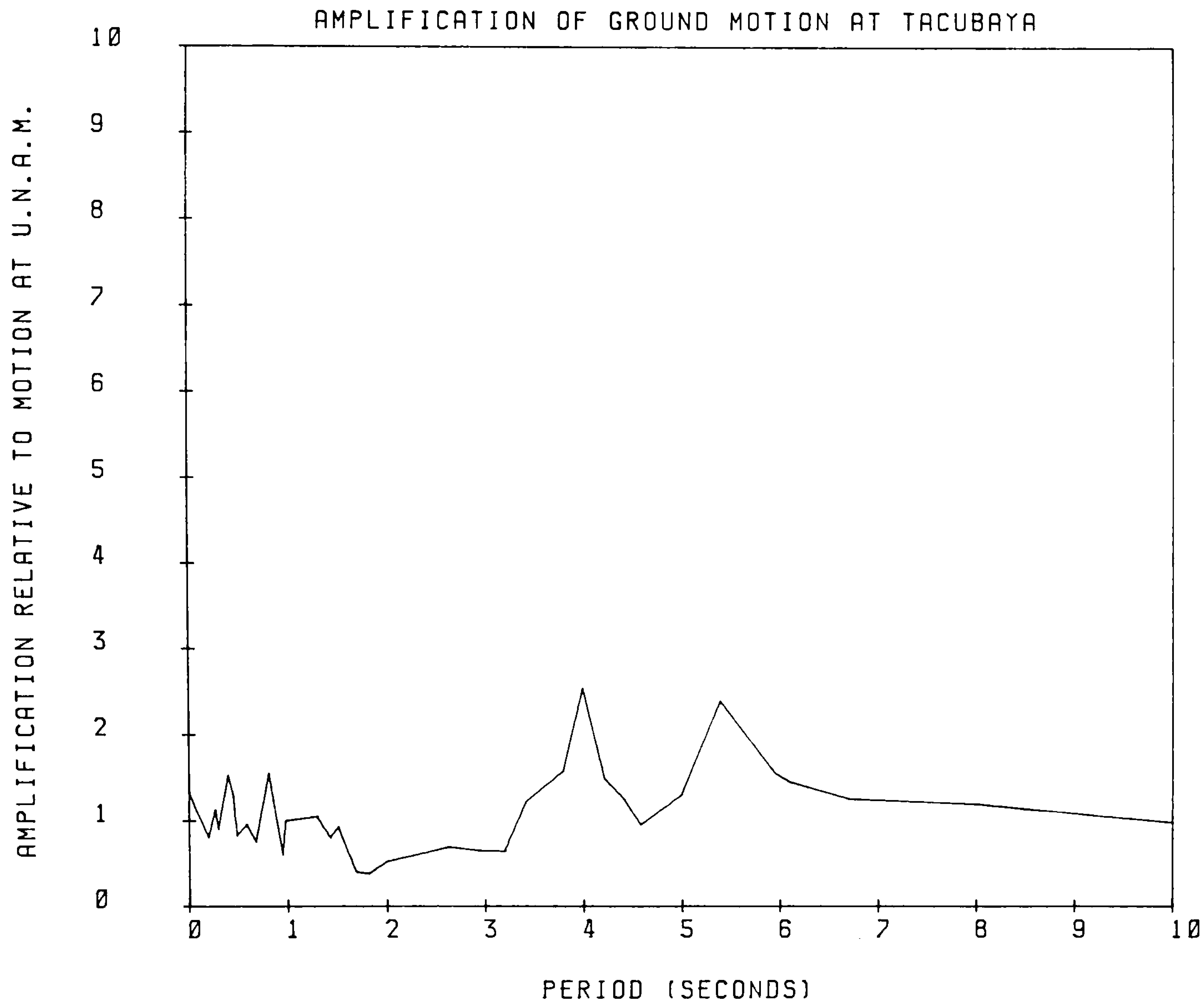
Source of data: Prince et al. (1985)

Figure 2.17



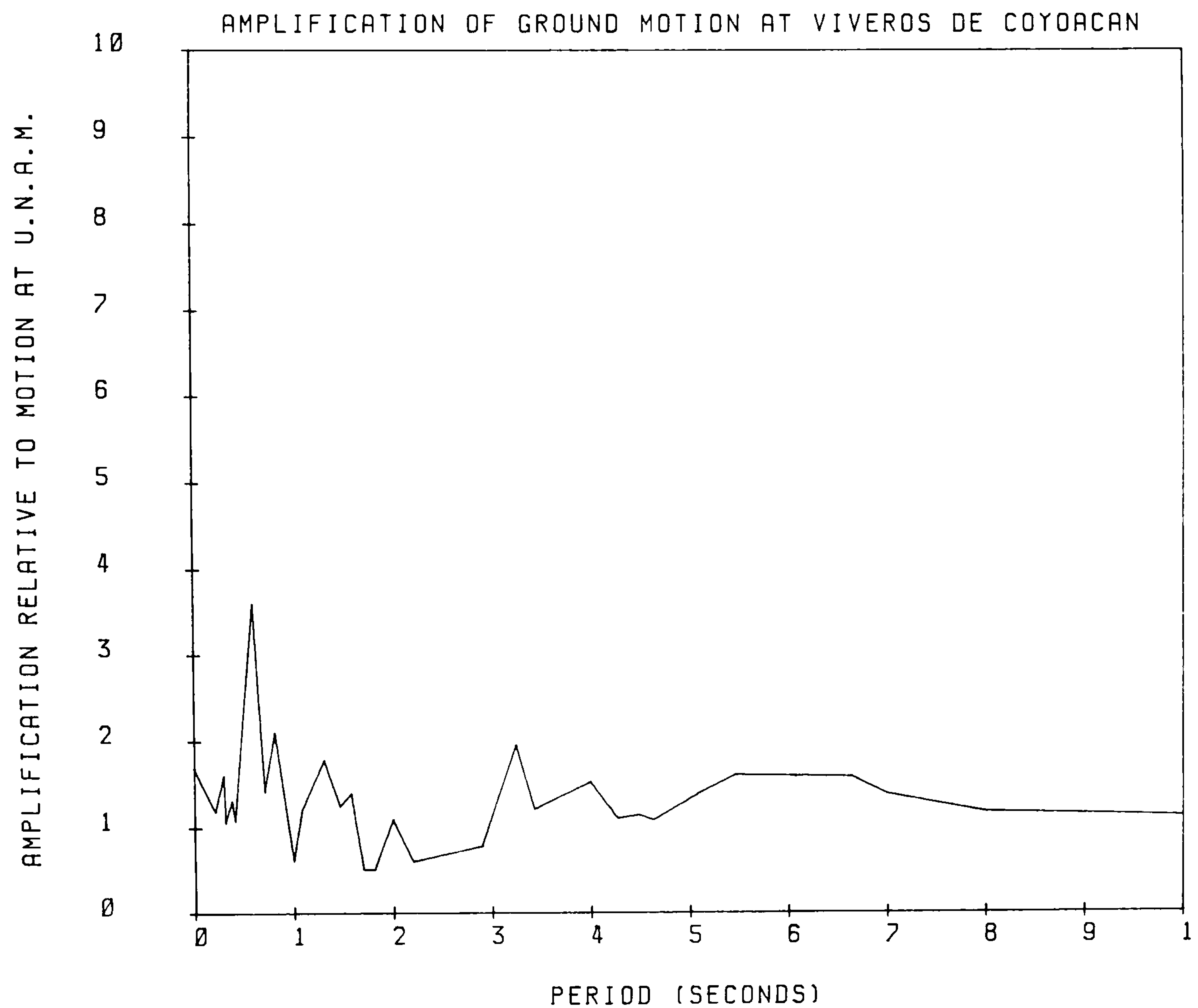
Source of data: Prince et al. (1985)

Figure 2.18



Source of data: Prince <u>et al</u>. (1985)

Figure 2.19



Source of data: Prince _et al_. (1985)

show the marked effect of the lake bed clays in amplifying the long period (low frequency) bedrock motions experienced during the earthquake. The clays were able to do this, because they themselves have long natural periods of vibration. These range from 1 to 3 seconds (Munich Re., 1986). They are therefore excited by all earthquake shock waves of this frequency, and act as a resonance amplifier for them.

Figure 2.16 shows that at SCT (Site 2), in the the western part of the lake zone, a phenomenal peak in amplification was produced at a period of 2 seconds (frequency of 0.5 Hertz). At this particular frequency of vibration, motion was up to 8 times more severe than that recorded at UNAM. Figure 2.17 shows that at Central de Abastos (Site 3), peaks in amplification were produced at periods of 2, 3 and 4 seconds (the highest peak was at 3 seconds). The increase in the dominant period of vibration between Sites 2 and 3, can probably be attributed to increased thickness of the Tacubaya clays away from the former lake margin (i.e. the transition zone - see Figure 2.15). Meli et al. (1985) have shown that the natural period of vibration of the lake bed clays increases with clay thickness.

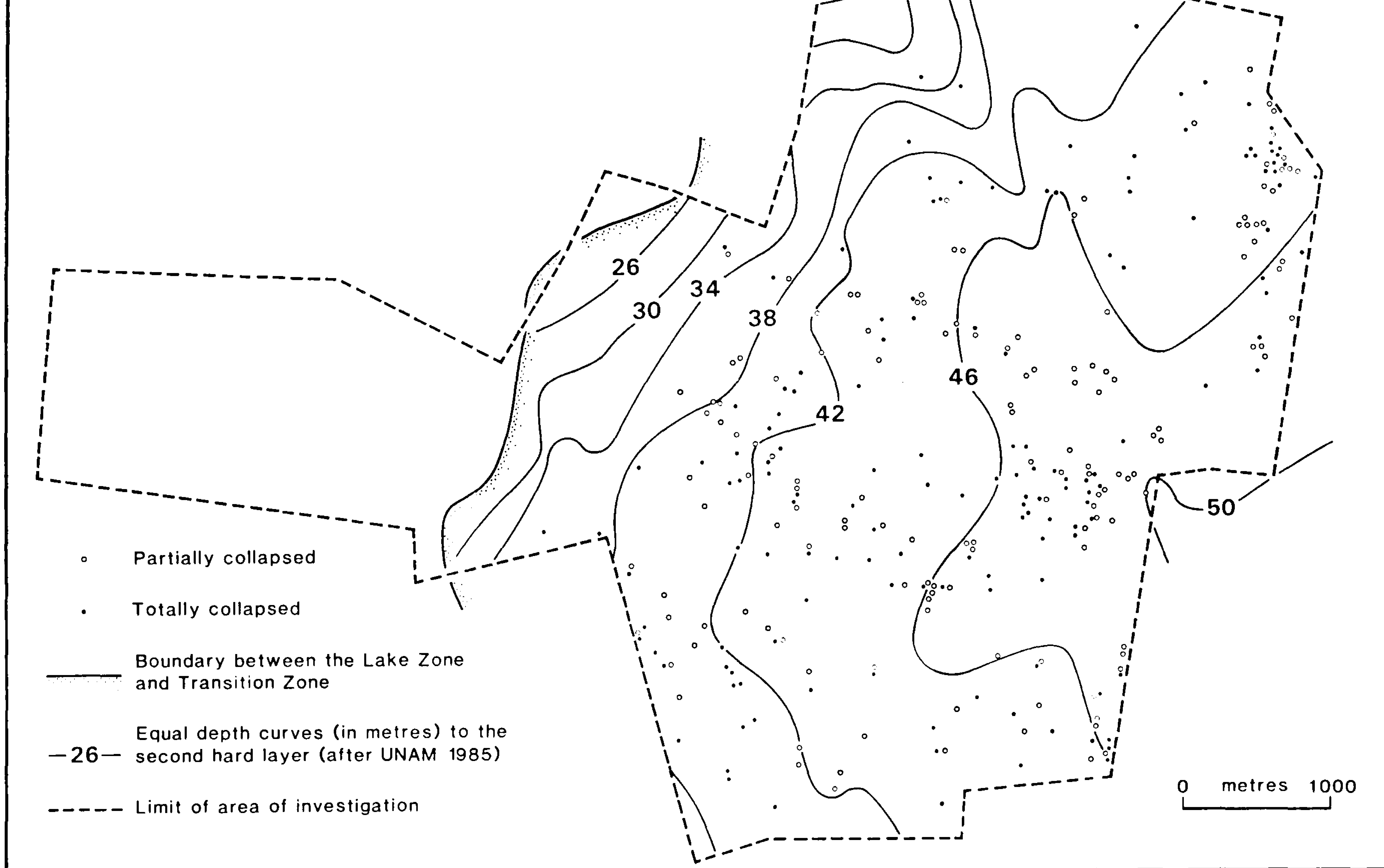
The dense soils of the transition and hill zones were not as excited by the long period motions experienced during the earthquake. As a result, they did not produce large peaks of amplification at these frequencies (see Figures 2.18 and 2.19).

2.10.2 Interpreting the damage distribution

It can be concluded that most of the earthquake damage in Mexico

Figure 2.20

Location of partially or totally collapsed buildings in relation to depth to hard deposits



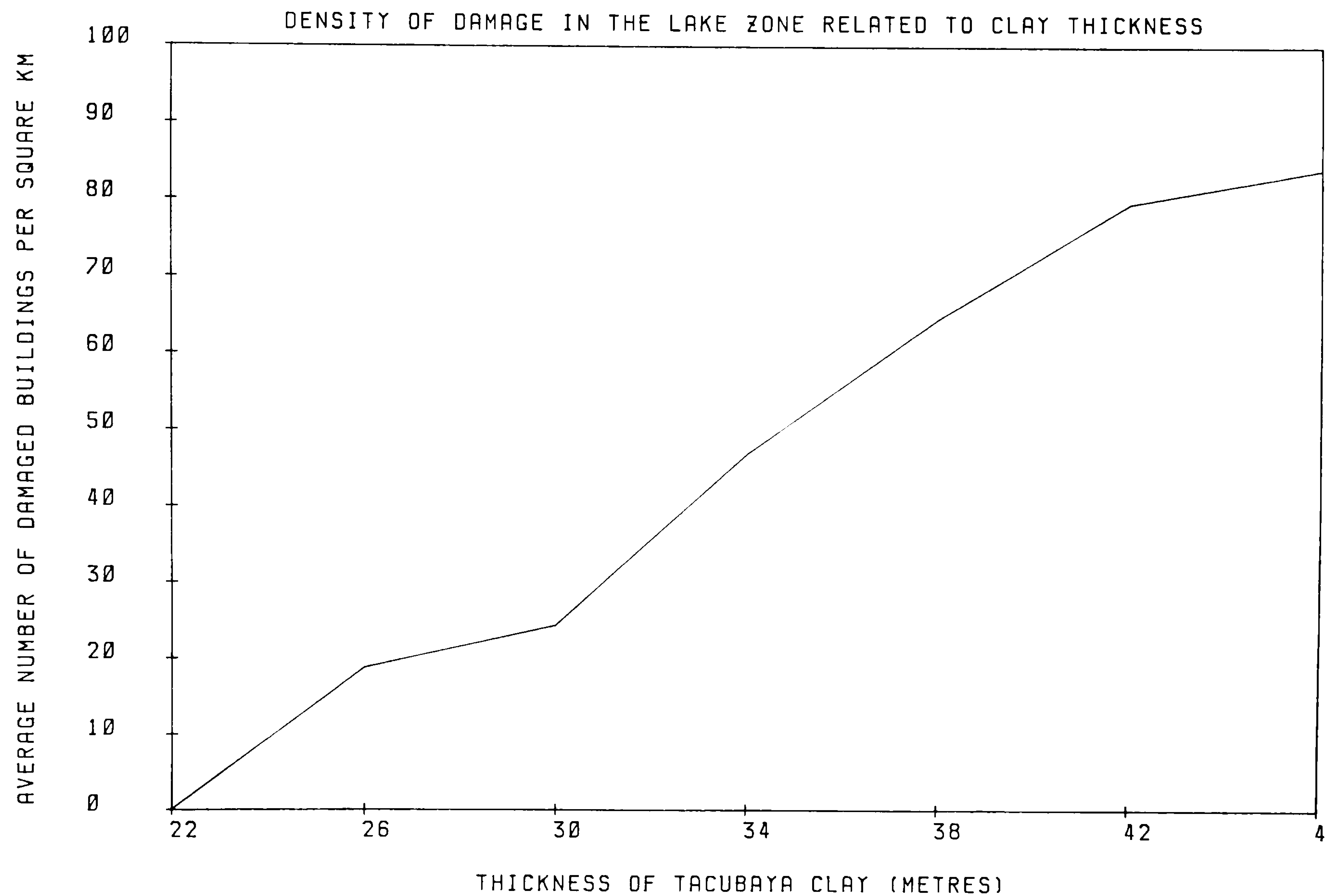
City was confined to the lake zone (see Figures 2.11 and 2.12), because ground motion on the lake bed was much more prolonged and violent than that experienced on adjacent subsoil units. It was the duration and cyclical nature of motion on the lake bed, together with the large horizontal ground displacements, that were probably responsible for most of the damage. Munich Re. (1986) have shown that large parts of the lake zone were shaken to and fro at intervals of 1 to 2 seconds (with displacements of between 10cm and 40cm) for almost an entire minute.

Figure 2.20 shows that within the lake zone, the most seriously damaged buildings (i.e. those that experienced partial or total collapse) were almost all confined to that part of the lake bed where the depth to the "second hard layer" (see Section 2.6) exceeds 37m. They tended to be concentrated where the layer is more than 42m below the surface. This can probably be attributed to increased amplification and prolonged duration of the earthquake ground motion, in response to the increased thickness of the Tacubaya clays. Further evidence of this is provided by Figure 2.21. This shows that in the area of investigation the density of damage on the lake bed increased with clay thickness.

2.10.3 Interpreting the vulnerability analysis

Figure 2.13 highlighted the greater vulnerability of medium to high-rise buildings in the lake zone to damage during the earthquake. This was probably caused by the lower natural frequencies associated with buildings of this elevation (in general, the taller a building the longer its natural period of vibration).

Figure 2.21


DENSITY OF DAMAGE IN THE LAKE ZONE RELATED TO CLAY THICKNESS
AVERAGE NUMBER OF DAMAGED BUILDINGS PER SQUARE KM
100
90
80
70
60
50
40
30
20
10
0
22
26
30
34
38
42
46
THICKNESS OF TACUBAYA CLAY (METRES)

In Mexico City, buildings of between 8 and 16 storeys usually have fundamental periods of between 1 and 2 seconds (Munich Re., 1986). Buildings in this height range were therefore very sensitive to the peak in amplification (at a period of 2 seconds), produced by clays in the western part of the lake zone (see Figure 2.16). The close similarity between the predominant period of vibration of the ground, and that of the medium to high-rise buildings, caused many of these structures to resonate during the earthquake. This had the effect of both reinforcing and prolonging the vibration, and accounts for their higher damage ratios (see also Section 2.11.2.2 for the effects of building "softening"). In contrast, low-rise buildings possessed natural periods of vibration that were less than those of the ground, while the periods of very tall structures were greater. These buildings were not as excited by the earthquake ground motion, and were therefore less severely shaken.

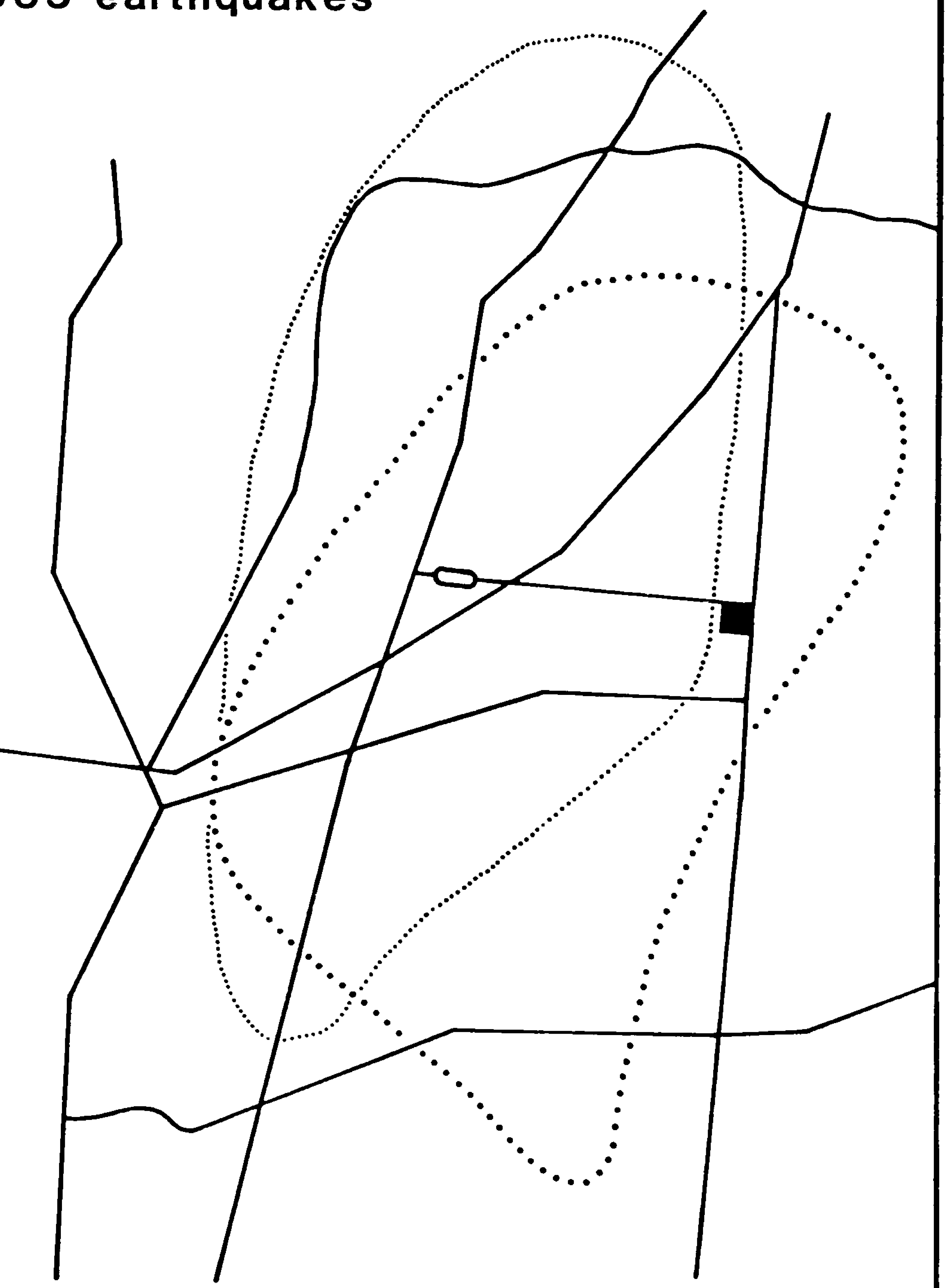
The effects of resonance may also help to explain why buildings of flexible construction experienced a higher incidence of damage than rigid ones. This is because the more flexible a building, the longer its natural period of vibration.

2.10.4 Building height and the area of major damage in the lake zone

The inset on Figure 2.9 shows that the area of major earthquake damage in Mexico City was of relatively small extent. It was restricted to the western part of the lake bed, with only minor damage occurring in adjacent lake bed areas. This seems discordant with the fact that severe ground motion was experienced across most of the lake bed during the earthquake. For example, see the ground

Figure 2.22

Location of the zones damaged in the 1957 and 1985 earthquakes



.... Zone with damage in 1957 (after Duke and Leeds, 1959)

.... Zone with major damage in 1985

0 km 1

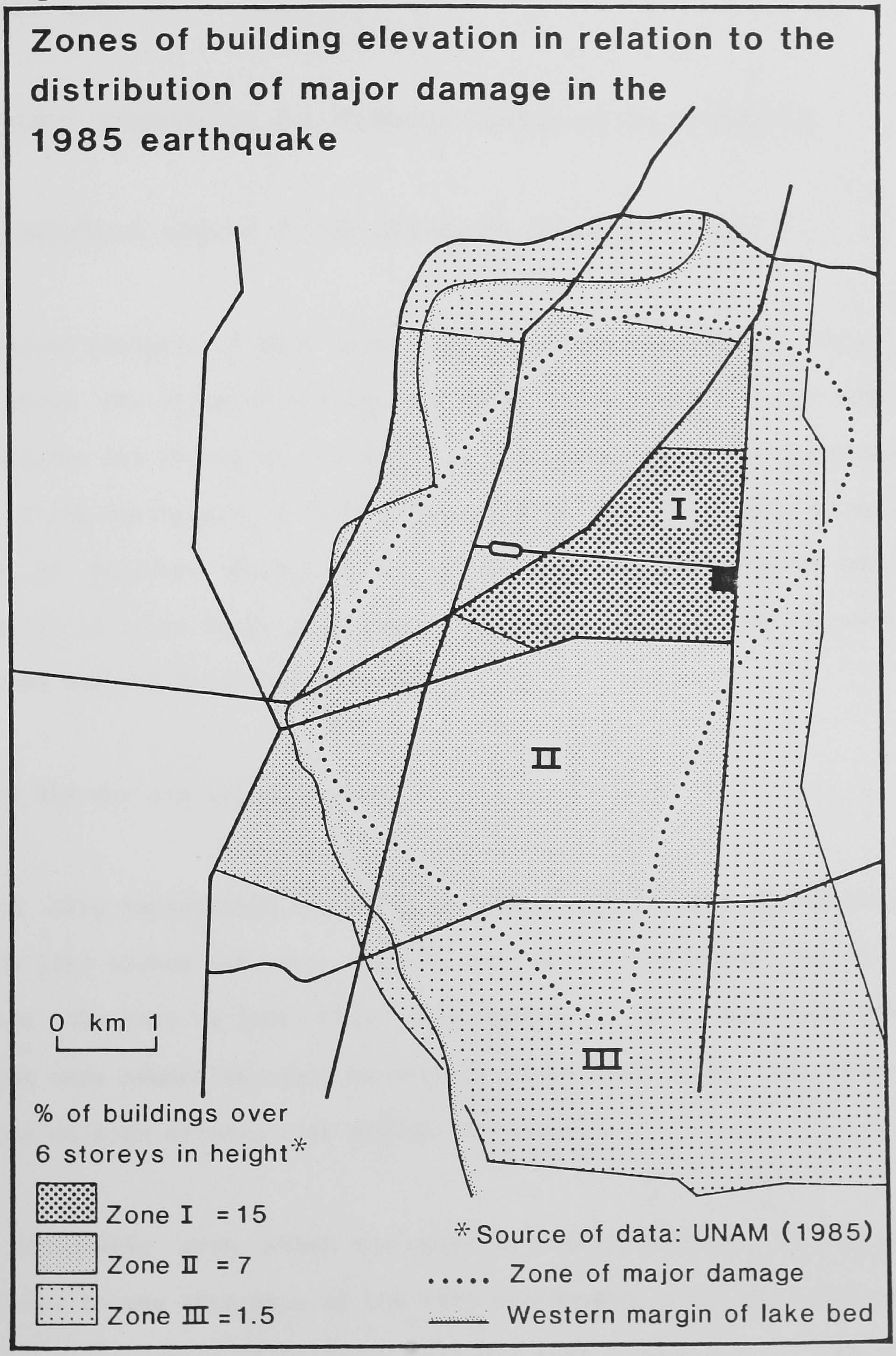
motion data pertaining to Central de Abastos (Site 3) in Table 2.4 and Figures 2.15 and 2.17.

It is interesting to note that the western part of the lake zone was also the area worst affected during the 1957 earthquake (see Section 2.4.3). Figure 2.22 shows the close correspondance between the zones of major damage experienced in the 1985 and 1957 earthquakes. It would seem to suggest a greater vulnerability of this part of the city (and/or lake bed), to the types of long period bedrock motion experienced during the earthquakes.

In the light of the discussion in Section 2.10.3, a possible explanation for this observation is provided by Figure 2.23. This shows three zones of building elevation in and around the area worst affected by the 1985 earthquake. For each, the percentage of buildings over 6 storeys high has been calculated. The figure shows that the area of major damage was largely confined to zones I and II, where the percentage of medium to high-rise buildings is greatest. It was very much restricted in zone III, where 98.5% of the buildings are less than 6 storeys high (low-rise). Unfortunately, no data are available for the remainder of the lake bed area, though it is known that beyond the margins of zone III most of the buildings are low-rise.

It would therefore seem that within the lake zone, the area of major damage was largely confined to that part of the city where the density of medium to high-rise construction is greatest. This would imply that had there been more high-rise buildings on the lake bed, the area of major damage experienced in 1985 (and 1957) would have

Figure 2.23


Zones of building elevation in relation to the distribution of major damage in the 1985 earthquake
I
II
III
0 km 1
% of buildings over 6 storeys in height*
Zone I = 15
Zone II = 7
Zone III = 1.5
*Source of data: UNAM (1985)
..... Zone of major damage
Western margin of lake bed

been of much greater extent. It is obviously imperative to ensure that steps are taken to regulate future development of this type in the lake zone.

PART THREE. ENGINEERING AND INSURANCE ASPECTS OF THE EARTHQUAKE

2.11 STRUCTURAL ASPECTS OF THE EARTHQUAKE DAMAGE IN MEXICO CITY

A detailed analysis of structural aspects of the earthquake damage is beyond the scope of the present study. This section simply aims to consider the nature of the building code that was in force at the time of the earthquake, and to summarise some of the more common types of building failure that were observed in Mexico City. Once again, it is to be hoped that important lessons will be be learned from the Mexican damage experience.

2.11.1 The Mexican building code

Mexico City established its first building code in 1942. Subsequent to the 1957 earthquake, new regulations were introduced for the Federal District in 1966. These were updated in 1976, such that the Mexican code became as rigid as many of those that apply in other regions of high seismic risk around the world.

The uniformity with which the codes have been enforced is open to question. In the aftermath of the 1985 earthquake, much of the blame for the large number of building failures that occurred in Mexico City was placed upon poor standards of design, workmanship and materials. However, it is important to realise that the intensity

TABLE 2.5

Major Causes of Building Failure in Mexico City

(as a % of 330 collapsed or badly damaged buildings that were surveyed)

Corner building	42
Collapse of intermediate floors	40
Collapse of upper floors	38
Neighbouring buildings hitting together	15
Pronounced asymmetry of building reinforcement	15
Inadequacy of foundation structures	13
Excessive loads	9
'Soft' ground-floor structures	8
Previous earthquake damage	5
Punching through of ceiling slabs	4
Short columns	3
Previous uneven settlement	2

Source: The Institute of Engineering (UNAM), as reproduced by the Munich Re. (1986; p.35) and duration of ground motion experienced in the lake zone during the earthquake were more severe than those contemplated by the 1976 code (Toledo, pers.comm.). Buildings designed entirely in accordance with this code were therefore understrength during the earthquake.

In the light of the earthquake damage experience, the Mexican building code was amended. Provisional regulations were issued in October, 1985, requiring buildings in the lake zone to withstand forces approximately double those allowed for in the 1976 code (Toledo, pers.comm.).

2.11.2 Common types of building failure in Mexico City

In Section 2.9.2.2, it was shown that the buildings most vulnerable to damage in the lake zone were medium to high-rise concrete structures. Several predominant causes of failure were observed in buildings of this type. Most of these can be attributed to the nature of the earthquake ground motion, or to weaknesses in design and construction. The major causes of loss are summarised in Table 2.5, and described below.

2.11.2.1 Column failure

The majority of concrete frame buildings that collapsed did so in a "pancake" fashion, such that floors became stacked one on top of the other (see Plate 2.1). This type of collapse seems to have been caused by column failure.

Engineers at UNAM have determined that concrete frame buildings

PLATE 2.1

"Pancake" collapse of a reinforced concrete frame building in the lake zone of Mexico City. The building was demolished shortly after the photograph was taken.

M.R.Degg (November, 1985)

PLATE 2.2

Damage caused by buffeting between adjacent reinforced concrete buildings in the lake zone. The gap separating the two buildings is clearly insufficient. The buildings are of different elevations, and this probably served to enhance the relative motion between them during the earthquake (due to their different natural frequencies of vibration)

M.R.Degg (November, 1985)


Escuela
75

performed very well during the initial period of ground shaking. In many buildings, column failure was only induced because of the long duration of the earthquake in the lake zone. With each successive cycle of ground motion, the concrete in the columns of the most responsive buildings deteriorated slightly. The capacity of these columns to withstand vertical loads was progressively reduced, until they eventually sheared and collapse occurred (UNAM, 1985).

It is beyond doubt that as far as the reinforced concrete structures of the lake zone are concerned, a major destructive aspect of the earthquake was the long duration of strong ground motion. Had this been reduced by half, considerably fewer buildings would have collapsed (Toledo, pers.comm.).

2.11.2.2 The effect of rigid infill walls

The presence of brittle infill walls that were insufficiently reinforced or anchored to the main structure, proved to be a vulnerable design feature of many buildings on the lake bed. Deterioration and brittle failure of these walls during the earthquake, resulted in abrupt changes in building stiffness. Ductility was effectively increased and, as a consequence of this "softening process", the period of vibration of buildings lengthened. Many low to medium-rise structures, with original periods of vibration less than those of the ground, therefore became increasingly vulnerable once they started to yield and "soften". This was especially significant because of the long duration of the strong motion in the lake zone.

The presence of infill walls that were sufficiently reinforced and secured undoubtedly saved many buildings from failure. This was particularly the case when the walls were symmetrically distributed, and thereby able to protect building frames by absorbing a large amount of the lateral load experienced during the earthquake.

Conversely, a non-symmetrical arrangement of rigid infill walls had an adverse effect upon some buildings. This is demonstrated by the large number of corner buildings that were badly damaged in the earthquake (see Table 2.5). These typically have glass street frontages, with rigid walls opposite them. The effect of such sharp contrasts in the flexibility of adjacent walls was to introduce torsion into the structures during the earthquake. Stress acting upon columns was thereby increased, and failure often resulted.

2.11.2.3 "Soft" storeys

Abrupt changes in stiffness between floors served to increase the vulnerability of some structures to damage. A number of damaged buildings combined rigid upper storeys, with a flexible ground floor storey that was essentially open (due to the need to accommodate a shop, garage or showroom). During the earthquake, lateral forces placed severe strain upon the unsupported pillars of the soft storey, often causing it to experience heavy damage or failure.

In other buildings, failure of infill walls at a particular level resulted in the formation of a soft storey with reduced rigidity. Pillars at the soft level frequently failed, because of the enormous increase in the amount of ductility demanded of them.

PLATE 2.3

Earthquake induced settlement of a 6 storey building in the Roma Norte district (of the lake zone) of Mexico City. The building was caused to sink between 0.5 and 1.2 metres below the surface, badly damaging the pavement in the process.

M.R.Degg (November, 1985)

PLATE 2.4

An old church (Iglesia de Loreto) in the lake zone of Mexico City demonstrates the effects of differential ground settlement. The church is situated approximately 600 metres to the north-east of the Zocalo (see Figure 2.9)

M.R.Degg (December, 1985)


HOTEL

2.11.2.4 Buffeting of adjacent buildings

Buffeting between inadequately spaced buildings was a relatively common cause of major and minor damage. Damage was most severe when buildings of different heights (and therefore different resonance periods - see Section 2.10.3), were constructed adjacent to each other. Under such circumstances, the top corner of the smaller building was able to pound against the side wall of the taller one.

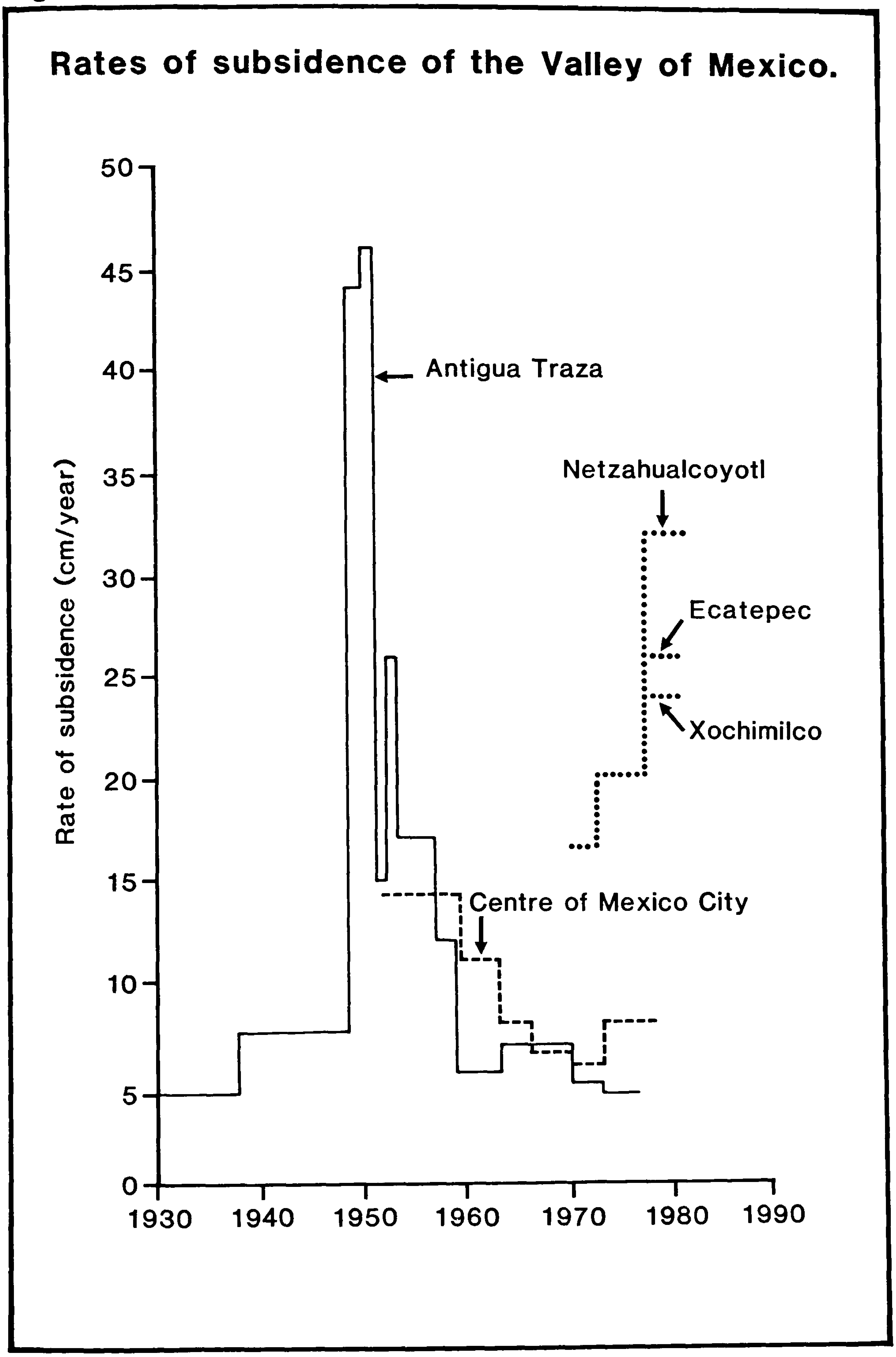
Buffeting damage was also severe when the walls and floors of two adjacent buildings were offset relative to one another. This enabled the rigid concrete floors of each building to pound into the walls of its neighbour (see Plate 2.2). The end result was frequently the collapse of both buildings.

2.11.2.5 Foundation failure

Very few buildings experienced foundation failure during the earthquake. Failure of superstructure was by far the most common cause of collapse. This is reflected in the fact that the majority of failed buildings collapsed without significant rotation.

Earthquake induced subsidence was observed in some buildings, commonly those with friction piles. Plate 2.3 shows that building subsidence in excess of 1m was observed in some cases. Conversely, many buildings with foundation piles (resting on stable sediment layers - see Section 2.6), were caused to "grow" out of the ground slightly by the earthquake. This was due to subsidence of the ground relative to the buildings.

Figure 2.24



After Fernandez (1985, Fig. 7)

2.11.2.6 Differential settlement

As mentioned in Section 2.6.1, subsidence is a very serious problem across much of the lake zone of Mexico City. It has historically been greatest in the old centre of the city, with settlement during the period 1891-1970 exceeding 7m around Alameda Square (i.e. that part of the city worst affected during the 1957 and 1985 earthquakes - see Figure 2.22). Subsequent to the 1957 earthquake, Duke and Leeds (1959) suggested that excessive settlement may have been a precursor to the large amount of damage experienced in the city centre.

Figure 2.24 shows that since the late 1950's, the rate of subsidence in the centre of Mexico City has slowed down. This is due to Government restrictions on water extraction. Conversely, it has increased dramatically in parts of the city further to the east, where large amounts of water are currently being withdrawn from the lake bed sediments for industrial and domestic purposes. For example, in Netzahualcoyotl to the south-east of the airport, and Ecatepec to the north of it. These areas, however, were not badly affected by the 1985 earthquake, probably due to the fact that construction within them is predominantly low-rise (see Section 2.10.4).

It is therefore very difficult to draw definite correlations between damage experienced in the 1985 earthquake, and recent rates of subsidence in the lake zone. Despite this, there is little doubt that differential settlement has resulted in many buildings standing out of plumb in the city centre (see Plate 2.4). It is possible that this may have increased the vulnerability of some structures to the earthquake ground motion.

2.11.2.7 Damage from previous earthquakes

In recent years, a number of damaging earthquakes have affected Mexico City (e.g. those of 1957, 1979 and 1981). Besides the weakening effect that these would have had upon many structures, there is evidence to suggest that standards of repair in some damaged buildings were poor. UNAM (1985) report that a number of buildings that collapsed in the 1985 earthquake had been improperly repaired following damage in previous earthquakes (e.g. some residential blocks in the Tlatelolco and Juarez housing estates).

2.11.2.8 Short columns

Short reinforced concrete columns proved to be a relatively vulnerable design feature of many buildings (UNAM, 1985). In short columns, shearing tends to prevail over bending when large lateral forces are applied. Many short columns were induced to fail as a direct consequence of the long duration of the earthquake.

2.12 THE EFFECT OF THE EARTHQUAKE ON THE INSURANCE INDUSTRY

Like the U.S. and Canadian fire policies, the standard Mexican fire policy provides cover for fires triggered by earthquake. Coverage for damage caused by earthquake shock may be included in the policy by means of a supplement and premium loading (Munich Re., 1986).

As mentioned in Section 2.1, the 1985 Mexican earthquake resulted in one of the largest earthquake losses ever experienced by the insurance industry.

2.12.1 The size of the insurance loss

The Munich Re. (1986) have conducted a relatively detailed analysis of the economic damage caused by the earthquake. They conclude that of the total economic loss of US$ 4,000 million, 87% was property damage (the remainder was consequential damage). Property damage was subdivided amongst the various sectors of the Mexican economy as follows:

Public administration	34%;
Residential buildings	16%;
Health Care	15%;
Education	11%;
Industry and Trade	6%;
Tourist Facilities	5%;
Other	13%.

Approximately US$ 275 million (7%) of the total economic loss is estimated to have been insured (US$ 175 million of this was in Mexico City). The total insurance loss was, therefore, not as great as might have been expected for an earthquake disaster of this size. The main reasons for this would seem to be:

a) Many privately-owned buildings that were damaged in the earthquake were not insured. It seems that once the 1957 earthquake had been forgotten, many property owners proved unwilling to buy insurance cover for earthquake shock. Although the 1985 earthquake created an upsurge in the demand for this class of insurance in Mexico City (Capurro, pers.comm.), it is highly likely that with time, owners will become increasingly reluctant to continue paying the premiums;

b) Many of the public buildings that were damaged do not seem to have been insured;

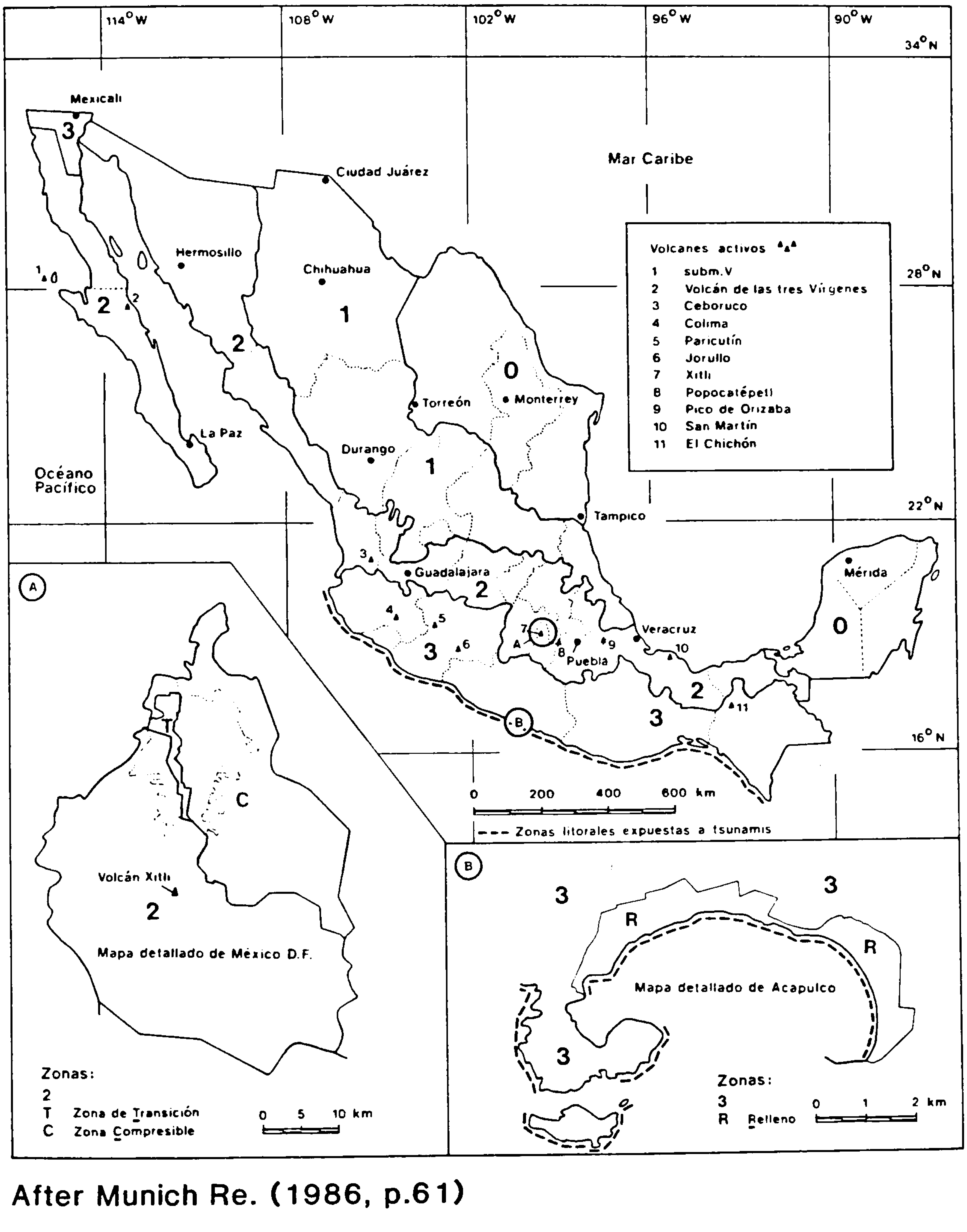
c) Of the buildings that were insured, many were underinsured. The main reason for this was that insured values had failed to keep pace with the rapid devaluation of the peso that took place in the years prior to the earthquake. The following table shows the falling value of the peso in relation to the dollar during this time period:

Pesos to the dollar

December of 1976	20	1985	J	215
1977	23		F	220
1978	23		M	226
1979	23		A	233
1980	23		M	239
1981	26		J	245
1982	149		Jl	348
1983	161		A	347
1984	209		S	389
			O	493
			N	>500

Source: Cole (1985; p.10)

Figure 2.25
The earthquake tariff zones of Mexico



After Munich Re. (1986, p.61)

Additional problems were caused by the high inflation rate in Mexico. This stood at approximately 42% in the autumn of 1985;

d) The earthquake triggered very few fires in Mexico City. Occasional buildings were gutted, but there was no major conflagration similar to that experienced in San Francisco (1906) and Tokyo (1922).

Fire triggered by earthquake is not a major hazard in Mexico City, mainly due to the absence of piped fuels. As mentioned in Section 2.4.5.6, most domestic gas is supplied by lorry and stored in tanks. This effectively removes the threat of explosions caused by fractured underground pipelines. In view of the large number of underground water pipes that were broken during the earthquake (see Section 2.4.5.3), this is a wise precaution to take. One major gas tank explosion occurred in the city, at the Regis Hotel. This was completely gutted by fire, which spread to several adjacent buildings killing a large number of people.

Another aspect which served to reduce the number of earthquake-triggered fires in the city, is the fact that very little wood is used in construction (Toledo, 1980). As was shown in Section 2.9.1, the majority of buildings are of concrete, brick or stone construction.

2.12.2 The Mexican earthquake tariff

Mexico has a well established earthquake tariff system. Figure 2.25 shows that the tariff is based upon a subdivision of the country

TABLE 2.6

The Mexican Earthquake Tariff Prior to the Disaster

Construction class	Basic premium in per mille							Multiplying factor applied to basic premium										
	Tariff zone							Construction			Height			Standard			Design	
	0	1	2	3	T	C	R	symmetrical	semi-symmetrical	asymmetrical	1–6 floors	7–11 floors	12 floors plus	industry	normal	luxury	antiseismic	not antiseismic
I	0.20	0.40	0.80	1.60	1.07	1.07	2.13	1	1.15	1.30	1	1.15	1.30	1	1.15	1.30	0.75	1
I a, II	0.27	0.53	1.07	2.13	1.60	2.13	2.66	1	1.15	1.30	1	1.15	1.30	1	1.15	1.30	0.75	1
III, V	0.27	0.53	1.07	2.13	2.13	2.13	2.66	1	1.15	1.30	1	1.15	1.30	1	1.15	1.30	0.75	1
II a, IV, VI	0.33	0.67	1.33	2.66	2.66	2.66	2.66	1	1.15	1.30	1	1.15	1.30	1	1.15	1.30	0.75	1
VII	0.20	0.40	0.80	1.60	1.60	2.13	2.13	1	1.15	1.30	1	1.15	1.30	1	1.15	1.30	0.75	1
VIII	0.33	0.67	1.33	2.66	2.66	5.33	5.33	1	1.15	1.30	1	1.15	1.30	1	1.15	1.30	0.75	1

Source: Munich Re. (1986; p.62)

into 7 earthquake hazard exposure zones (see also Figure 2.8). These zones are as follows:

Zone 0: low exposure;

Zone 1: moderate exposure;

Zone 2: high exposure;

zone 3: very high exposure;

Zone T: transition zone (Mexico City only);

Zone C: lake zone (Mexico City only);

Zone R: soft sediments (Acapulco only).

The appropriateness of this zonation was demonstrated by the fact that the vast majority of damage in the 1985 earthquake was restricted to the zones of high risk, i.e. Zone 3, and Zone C (the lake zone) of Mexico City. Insurers should, therefore, continue to adhere strictly to this zoning system in the future.

The tariff that was in force at the time of the earthquake is shown in Table 2.6. Earthquake premiums are derived from this on the basis of hazard exposure (taken from Figure 2.25), the type of construction, the number of floors, and other criteria relevant to the risk.

Following the damage experience of 1985, it became apparent that the tariff needed considerable amendment. It clearly did not charge enough for buildings of high risk, yet penalised low risk structures unnecessarily. Take, for example, buildings of construction class I. According to Table 2.6, the basic premium to be charged for a building of this type in the transition zone (Zone T) of Mexico

City, is the same as that to be charged for one in the lake zone (Zone C), i.e. 1.07 permille. In view of the fact that the vast majority of damage experienced during the 1985 earthquake was in the lake zone (and that buildings in the transition zone were virtually unaffected), this seems very unfair.

In order to redress this imbalance, the tariff was amended in October, 1986. According to CRESTA (1987), the amendments to the basic premium rates for the Valley of Mexico are as follows (the first figure relates to construction class I, and the second to construction class VIII):

Zone 2: from 2.0 to 3.33 permille;

Zone T: from 3.48 to 8.65 permille;

Zone C: from 4.28 to 21.32 permille.

All the premium rates have clearly been raised quite substantially relative to those given in Table 2.6. The largest increases are for buildings in the lake zone (Zone C). The rates for this zone are now higher than those for any other part of the Valley of Mexico.

Unfortunately, no data are available concerning the multiplying factors (loadings) that need to be added to the basic premium. It is to be hoped that these have also been changed. In particular, it would appear essential that the loadings charged for medium to high-rise buildings in Zone C are substantially increased from their 1985 levels. This is to enable the premium to reflect the much greater vulnerability of these structures to motions on the lake bed (see Sections 2.9.2.2 and 2.10.3).

2.12.3 Accumulation control

Insurers and reinsurers must constantly monitor their earthquake liability accumulations, to enable them to accurately control their commitments. In this context, Mexico has an established accumulation assessment system based on a subdivision of the country into 18 accumulation assessment zones.

The 1985 earthquake highlighted some inadequacies in the use of standard accumulation assessment and control procedures in Mexico City. As a result, some Mexican direct insurers (with excess of loss reinsurance treaties), were more badly affected by the earthquake than was necessary.

In view of the great concentration of insured values within Mexico City (and the Valley of Mexico), it is imperative that established procedures of accumulation assessment and control are strictly adhered to.

2.12.4 Possible future earthquake losses

Although the 1985 earthquake took a heavy toll of human life, future earthquakes in Mexico could prove to be more costly in economic terms. As discussed in Section 2.3.2, an earthquake in the Guerrero seismic gap (see Figure 2.4) could be particularly destructive, because of its potential to affect Acapulco as well as Mexico City.

A large onshore earthquake, with its epicentre closer to Mexico City than the 1985 event, would also have the potential to be particularly damaging (Toledo, pers.comm.). Under such circumstances, Mexico City would be shaken by both high frequency and low frequency shock waves (high frequency shock waves rapidly attenuate with increasing distance from an earthquake epicentre - see Section 2.10.1). These would excite a wider range of subsoil types and building heights than the predominantly low frequency shock waves experienced during the 1985 earthquake. The economic loss would be particularly severe if the industrial areas in the northern part of Mexico City were affected.

It is essential that insurers and reinsurers are not led into a false sense of security, simply because a major earthquake occurred in Mexico in 1985. The likelihood of another large earthquake striking the western part of the country is, in reality, no less today than it was prior to the 1985 event. Indeed, as was shown in Section 2.3.2, the 1985 earthquake may well have slightly increased the possibility of another large earthquake in Mexico in the near future.

2.13 SUMMARY - IMPLICATIONS OF THE MEXICAN DISASTER FOR EARTHQUAKE HAZARD AND RISK ASSESSMENT

"Probably the only positive aspect about major disasters is that they query old and possibly outdated concepts, and thus provide a margin for new developments" (Munich Re., 1986; p.59).

Of all the major earthquake disasters that have occurred in recent years, few have had as profound and far-reaching implications as the 1985 Mexican earthquake. This disaster demonstrated for the first time, just how vulnerable a modern high-rise city can be to a distant earthquake event. It proved that earthquake hazard and risk assessments now need to consider the threat posed to cities many hundreds of kilometres away from the most active seismic belts.

The purpose of this section is to summarise the major findings of the Mexican earthquake, and to attempt to assess their implications for earthquake hazard and risk assessment in other parts of the world (including the Middle East).

2.13.1 The influence of subsoil on exposure to earthquake hazard

Above all else, the Mexican earthquake demonstrated the strong influence of surficial geology in controlling the severity of ground motion experienced during earthquakes. In the epicentral region of the earthquake, for example, the motions (and damage) recorded on the water-saturated sediments of the Balsas delta were much greater than those recorded on crystalline bedrock. However, it was in Mexico City that the importance of subsoil conditions was most cruelly and convincingly displayed.

A detailed analysis of the distribution of damage in the city, showed that it was almost exclusively restricted to the saturated clay deposits of an old lake bed. These served to amplify the shock waves by a factor of 6 (compared to the motions recorded on solid rock nearby). Furthermore, there is evidence to suggest that the thickness of the clay deposits served to control the amplitude, duration and predominant period of the earthquake ground motion (thereby exerting a direct influence on the density and severity of damage experienced). The most severely damaged buildings were largely confined to that part of the lake bed where the thickness of the clay exceeds 37m.

All in all, the Mexican damage experience demonstrates the value of detailed analysis of the geological conditions that underlie major cities in seismic regions. Through such analysis, it should be possible to identify subsoil units that are likely to increase the destructive forces of earthquakes. Data concerning these units should then be incorporated in hazard zonation maps, and used as a basis for implementing measures aimed at reducing the size of future earthquake losses (i.e. planning, design and construction regulations).

2.13.2 The vulnerability of buildings

Within the lake zone of Mexico City, rigid structures performed better than flexible ones. The greatest single influence on building vulnerability, however, was height of construction. Buildings between 6 and 20 storeys (medium to high-rise) were worst affected by the ground motion, with those between 9 and 11 storeys experiencing the highest incidence of damage.

Medium to high-rise buildings have lower natural frequencies of vibration than low-rise buildings. They were therefore much more sensitive to the long period ground motions experienced in Mexico City during the earthquake. It is beyond doubt that had there been no high-rise structures on the lake bed, the amount of damage would have been drastically reduced.

The fact that high-rise buildings are sensitive to earthquakes over much greater distances than low-rise ones, is something that is becoming of increasing concern and relevance. Not least of all, this is because there has been (in recent years) a global boom in the number of "sky scraper" cities. Many of these are situated in seismic belts or along their margins. The increased elevation of the cities means that some will start to experience earthquake damage for the first time, whilst others (like Mexico City) will find themselves increasingly vulnerable to larger and more frequent losses than those experienced in the past.

2.13.3 Building-subsoil interaction

The Mexican damage experience highlights the importance (in seismic regions) of trying to relate the dynamic characteristics of a building, to those of the subsoil on which it is situated. The vulnerability of a structure to damage is considerably increased if the resonance period of the subsoil and that of the structure coincide.

This was demonstrated to devastating effect on the lake bed of Mexico City. Parts of the lake zone witnessed a resonance coupling between the predominant periodicity of the earthquake shock waves, the natural period of vibration of the lake bed clays, and the natural periods of vibration of the medium to high-rise buildings. The inevitable result was a greatly prolonged and enhanced earthquake motion within these buildings.

Many of the world's major cities stand upon poor subsoil foundations (i.e. on water-saturated sediments in river valleys, or on coastal plains). In many cases, however, possible resonance couplings between the subsoil and buildings (and long period shock waves from distant earthquake events) have not been examined. This is yet another reason why earthquake hazard zonations need to focus greater attention upon the influence of surficial geology.

2.13.4 The analysis of earthquake recurrence

The 1985 Mexican earthquake occurred in a seismic gap along the Central American trench. This gap had been identified several years prior to the earthquake, on the basis of detailed analysis of the historical and 20th century seismic activity of the country (involving the compilation of comprehensive earthquake catalogues). The analysis highlighted a number of other seismic gaps along the trench. It is therefore likely that Mexico will experience at least one more large subduction zone earthquake before the turn of the century.

Seismo-tectonic analysis of this type is invaluable in helping to delineate the distribution of earthquake hazard in a country. It can also help to identify spatial and temporal patterns in earthquake activity. These can then be used as the basis for predicting (in general terms) when and where earthquakes are most likely to occur next.

2.13.5 Vulnerability to catastrophic loss

The Mexican earthquake has highlighted the dangers associated with the over-concentration of people and investment in seismic areas. Clearly, the larger the number of people and the greater the economic wealth in earthquake regions, the greater the potential for catastrophic losses. Indeed, it is the combination of high hazard exposure and over-concentration of people and economic investment, that serves to make Mexico City the world's archetypal vulnerable city. It is in cities of this type around the world that every precaution needs to be taken to mitigate earthquake hazard.

2.14 CONCLUSIONS

The 1985 Mexican earthquake ranks foremost amongst the most disasterous earthquakes to have affected the insurance industry. In terms of overall insurance loss, the event is superseded only by the Tokyo earthquake of 1923, and the San Francisco earthquake of 1906.

The purpose of this chapter has been to describe an investigation into the Mexican earthquake, aimed at identifying the factors that serve to control the severity of earthquake impact upon a country (and in particular, upon a large metropolitan area like Mexico City). Data of this type, which lead to a greater understanding of earthquakes and their effects, are a primary requirement in the delineation of earthquake hazard and risk.

It is to be hoped that the lessons learned from the Mexican earthquake (as summarised in Section 2.13) will lead to more precise hazard and risk evaluations in other seismic regions of concern, thereby helping to reduce vulnerability to large earthquake losses. The remainder of the study is dedicated to such an analysis of the Middle East.

CHAPTER 3. THE MIDDLE EAST - A REGION OF CONCERN

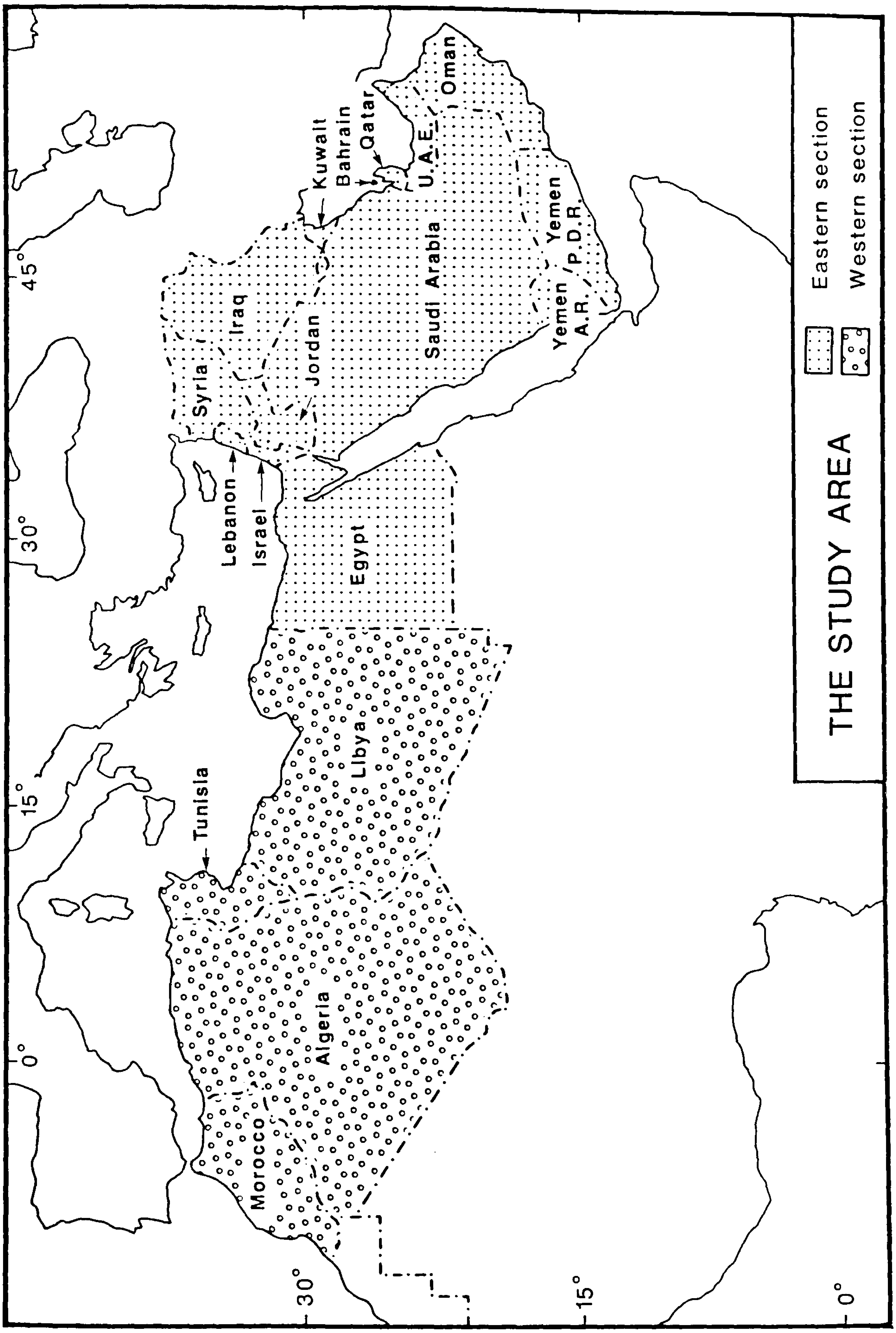
3.1 INTRODUCTION

It has been estimated that between the years 1900 and 1979, at least 160,000 people were killed in the Middle East by earthquakes (Perera, 1979). The same author concludes that between 1953 and 1979, some 800 Middle Eastern villages were destroyed by earthquake activity, and over 500,000 people made homeless. Indeed, the entire Middle Eastern region has a long and continuous history of earthquake disasters. This led Cidlinsky and Rouhban (1983) to conclude that no country in the Middle East "can be considered to be free from seismic hazards" (p.7).

One must assume that earthquake disasters will continue to occur in the Middle East in the future. Furthermore, there is every reason to expect that future earthquakes will exact an ever increasing toll in human and economic loss. In view of this, it is hardly surprising that the Middle East has become a region of increasing concern to the insurance industry.

The purpose of this chapter is to analyse the major reasons for the increased vulnerability of the Middle East to earthquake hazard. The implications of this for the insurance industry are discussed. Emphasis is placed on the need for more precise evaluations of earthquake hazard for insurance and reinsurance purposes, in order to mitigate the escalating earthquake risk. The chapter concludes with a brief description of the methodology of earthquake hazard assessment that has been applied in the Middle East.

Figure 3.1



THE STUDY AREA
Eastern section
Western section
Morocco
Algeria
Tunisia
Libya
Egypt
Israel
Lebanon
Syria
Iraq
Jordan
Kuwait
Bahrain
Qatar
U.A.E.
Oman
Saudi Arabia
Yemen A.R.
Yemen P.D.R.
0°
15°
30°
45°

3.2 THE "MIDDLE EAST" DEFINED

Definitions of the term "Middle East" vary quite considerably. According to Fisher (1978), the term was first used in the early years of the present century to describe an area around the Persian Gulf. It formed a logical intermediate definition (in a world centred on Europe), between the Mediterranean "Near East", and the "Far East".

During the Second World War, the area referred to as the "Middle East" gradually increased in size, to cover a military province stretching from Iran to Libya. The term "North Africa" was often used to designate a subregion of the "Middle East" that extended across the whole of the African continent, between the Mediterranean Sea and the Sahara Desert (Beaumont et al., 1976).

A wide variety of alternative interpretations of the term "Middle East" have since been proposed. All the definitions are to some extent subjective, and none is wholly clear and unambiguous. The region that is analysed in this study is shown in Figure 3.1. It incorporates countries from both North Africa and south-west Asia. The main reasons for including all these countries in the study area are:

a) In addition to political frontiers, there are identifiable natural boundaries around a Middle Eastern region defined in this way. These include:

-the Zagros mountain ranges of the Iran-Iraq border;

-the mountains of the Kurdistan region, along the Syria-Turkey border;

-the Sahara Desert of North Africa;

-the shorelines of the Mediterranean Sea, Red Sea and Arabian Sea.

b) Several of the aforementioned physical boundaries are related to tectonic processes operating in the region. These processes are to some extent inter-related (as will be shown in later chapters), and are responsible for generating the vast majority of earthquakes felt in the region. In order for it to be comprehensive, an assessment of earthquake hazard in this part of the world therefore needs to incorporate data taken from all the countries shown in Figure 3.1. Ideally, data from other countries (notably Iran and Turkey) should also be included. However, these were omitted from the analysis due to time restrictions.

c) The countries included in the study area are linked culturally - with the notable exception of Israel, they are all Arab countries. Indeed, the only Arab countries omitted from the study area are Djibouti, Mauritania, Somalia and Sudan, for which only limited data are in any case available.

d) All the countries shown in Figure 3.1 have, to a lesser or greater extent, been linked throughout history. As will be demonstrated in later chapters, this is of importance in a study of this kind.

Figure 3.1 shows that the study area has been divided into two parts; an eastern section and a western section. The reasons for this will become apparent later in the study.

3.3 THE ESCALATING EARTHQUAKE RISK IN THE MIDDLE EAST

The Middle East is one of several regions in the world where the threat posed by earthquakes to mankind is becoming increasingly significant. This is not necessarily due to an increase in the seismicity of the region, but because Middle Eastern countries are allowing themselves to become more and more vulnerable to earthquake hazard (as, indeed, to other types of natural hazard). As a result of this, the potential for severe earthquake losses in the region is increasing, both in terms of loss of life and economic loss.

The main reasons for the escalating earthquake risk in the Middle East are:

- Rapid population growth, which has resulted in increased densities of population;

- The increased urbanisation of populations;

- The formation of large urban agglomerations, and associated over-concentration of people and economic investment;

- The rapid economic advancement of recent years, and improved standards of living associated with this;

TABLE 3.1

Population Data for the Middle East

Country	Population Estimate mid-1977[1] (millions)	Population Estimate mid-1987[2] (millions)	% Increase in Population 1977-1987	Natural Increase (annual %) 1987[2]	Surface Area (km^2) 1985[3]	Population Density per km^2 (1987)
Algeria	17.8	23.5	32	3.2	2,381,741	9.9
Bahrain	0.3	0.4	33.3	2.8	622	643.1
Egypt	38.9	51.9	33.4	2.6	1,001,449	51.8
Iraq	11.8	17.0	44.1	3.3	434,924	39.1
Israel	3.6	4.4	22.2	1.7	20,770	211.8
Jordan	2.9	3.7	27.6	3.7	97,740	37.9
Kuwait	1.1	1.9	72.7	3.2	17,818	106.6
Lebanon	2.8	3.3	17.9	2.2	10,400	317.3
Libya	2.7	3.8	40.7	3.0	1,759,540	2.2
Morocco	18.3	24.4	33.3	2.5	446,550	54.6
Oman	0.8	1.8	62.5	3.3	212,457	6.1
Qatar	0.1	0.3	200.0	3.0	11,000	27.3
Saudi Arabia	7.6	14.8	94.7	3.1	2,149,690	6.9
Syria	7.8	11.3	44.9	3.8	185,180	61.0
Tunisia	6.0	7.6	26.7	2.5	163,610	46.5
U.A.E.	0.2	1.4	600.0	2.6	83,600	16.7
Yemen A.R.	5.6	6.5	16.1	3.4	195,000	33.3
Yemen P.D.R.	1.8	2.4	33.3	3.0	332,968	7.2
Total	130.1	179.9	38.3	-	9,505,059	18.9
U.K.	56.0	56.8	1.4	0.2	244,046	232.7
World	4,083	5,026	23.1	1.7	146,666,667	34.3

Sources of data: (1) Population Reference Bureau Inc. (1977) World Population Data Sheet, Washington (U.S.A.):P.R.B.
(2) Population Reference Bureau Inc. (1987) World Population Data Sheet, 25th ed., Washington(U.S.A.):P.R.B.
(3) United Nations (1987) Demographic Yearbook 1985, 37th Issue, New York: U.N., 1099pp.-Table 3.

- The industrialisation that has taken place in many Middle Eastern countries, leading to the development of large industrial complexes (e.g. petrochemical plants);

- The development of marginal areas that are more exposed to the earthquake threat.

3.3.1 Population growth and density

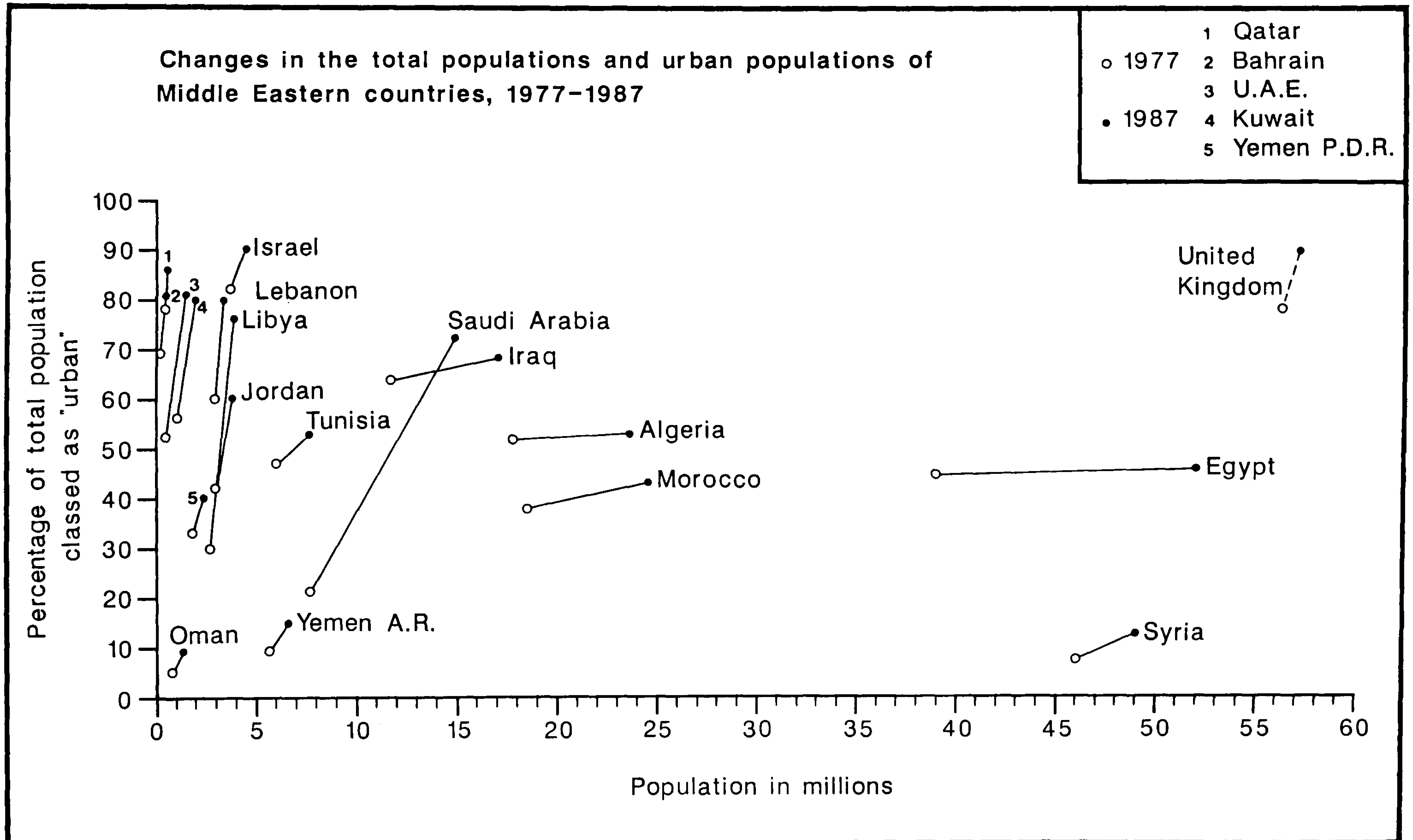
Population densities are constant neither in space nor time, and in the Middle East are increasing at an alarming speed. This is due to the rapid rates of population growth that have recently been witnessed in many parts of the region.

3.3.1.1 Population growth

For a variety of reasons, modern demographic data for Middle Eastern countries are often inadequate, unreliable, or both. Nevertheless, the broad characteristics of the region's population can be ascertained from those data that are currently available.

Table 3.1 shows that in the last 10 years, the total population of the Middle East has increased from 130 million (1977) to 180 million (1987). This represents a 38% increase in total population numbers. By way of comparison, the global population increased by 23% during the same time period, whilst that of the U.K. by only 1%. The Middle East has therefore been experiencing very rapid population growth in recent years, that is considerably greater than the global average.

Figure 3.2



Source of data: Tables 3.1 and 3.2

Within the Middle East, percentage increases in population during the last 10 years have varied quite considerably between different countries. Relatively speaking, the largest increases have been observed in the oil-rich states of the Arabian peninsula (see Table 3.1). For example, in the United Arab Emirates (600%), Qatar (200%) and Saudi Arabia (95%). These large percentage increases are mainly due to the immigration of a large number of people to work in industries associated with the economic boom. It should, however, be stressed that total populations in the Gulf States are relatively small. Absolute population increase in the Gulf region is therefore less impressive than relative growth. Figure 3.2 compares the changes in the total populations of Middle Eastern countries. It serves to illustrate that the absolute population growth of a country like Egypt (13 million), is much more impressive than its relative growth.

During the same time period, the smallest percentage increase in population was observed in the Yemen Arab Republic (16%). War-torn Lebanon also experienced a low percentage population increase (18%), as did Israel (22%).

Table 3.1 also shows that current rates of population growth vary quite considerably between different Middle Eastern countries. All the Arab states show rates that are greater than the current world average, whereas Israel shows a rate that is equal to it. Rapid population increase in the region is attributable to:

- The persistence of high birth rates;

- A sharp decline in death rates, particularly those associated with infants. This has resulted from improved medical facilities.

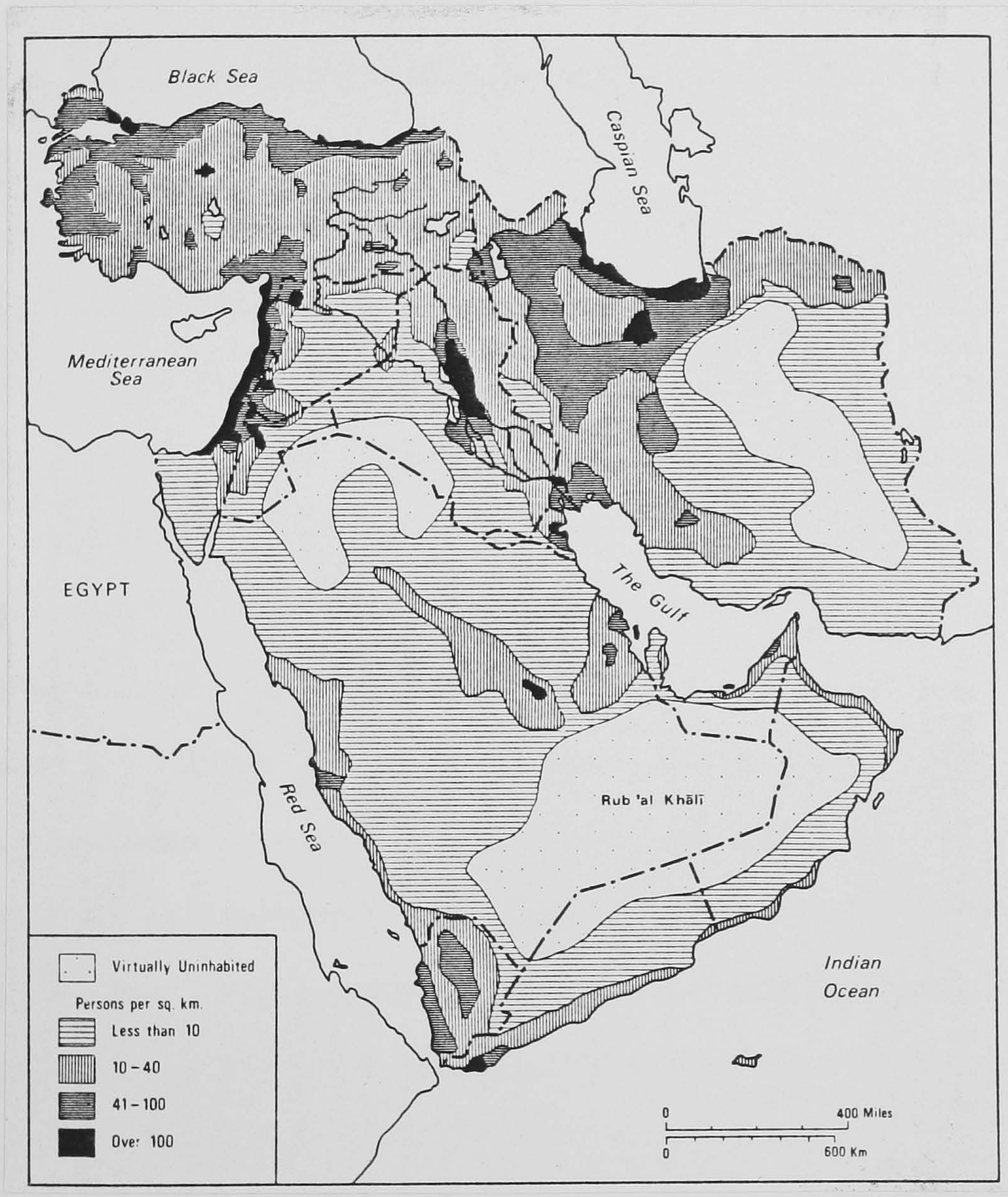
The persistance of high birth rates is due to a number of factors, most important of which is the difficulty of persuading devout Muslims (particularly the less well educated), that contraception is compatible with the teachings of Islam. It is for this reason that the populations of the Arab countries are growing at a much faster rate than that of Israel (which obviously has a substantial non-Muslim population).

3.3.1.2 Population density

The Middle East is one of the least densely populated areas of the world (Beaumont et al., 1976). However, recent rapid population growth has caused the overall population density of the region to rise sharply, from approximately 14 persons per square kilometre (1977) to 19 per square kilometre (1987). This density will continue to increase at a rapid rate, so long as the present rates of population growth are sustained.

An overall population density of 19 persons per square kilometre may not, at first, seem particularly high. It is important to realise, however, that the distribution of population within the Middle East is by no means uniform. Indeed, the entire region is characterised by very sharp contrasts in population density. The main reason for these is the presence of large tracts of arid or semi-arid land, that have historically proven unfavourable for permanent settlement. Only limited areas provide sufficient water to sustain high

Figure 3.3
Distribution and density of population in south-west Asia, 1972



After Beaumont *et al.* (1976, p.185)

population densities. Some of these areas are highlighted in Figures 3.3 and 3.4, which show population densities in 1972 for parts of the Middle East. The density values are obviously dated, but the overall pattern of population distribution in 1987 has changed little from that in 1972.

Areas of high population density in the Middle East tend to be associated either with:

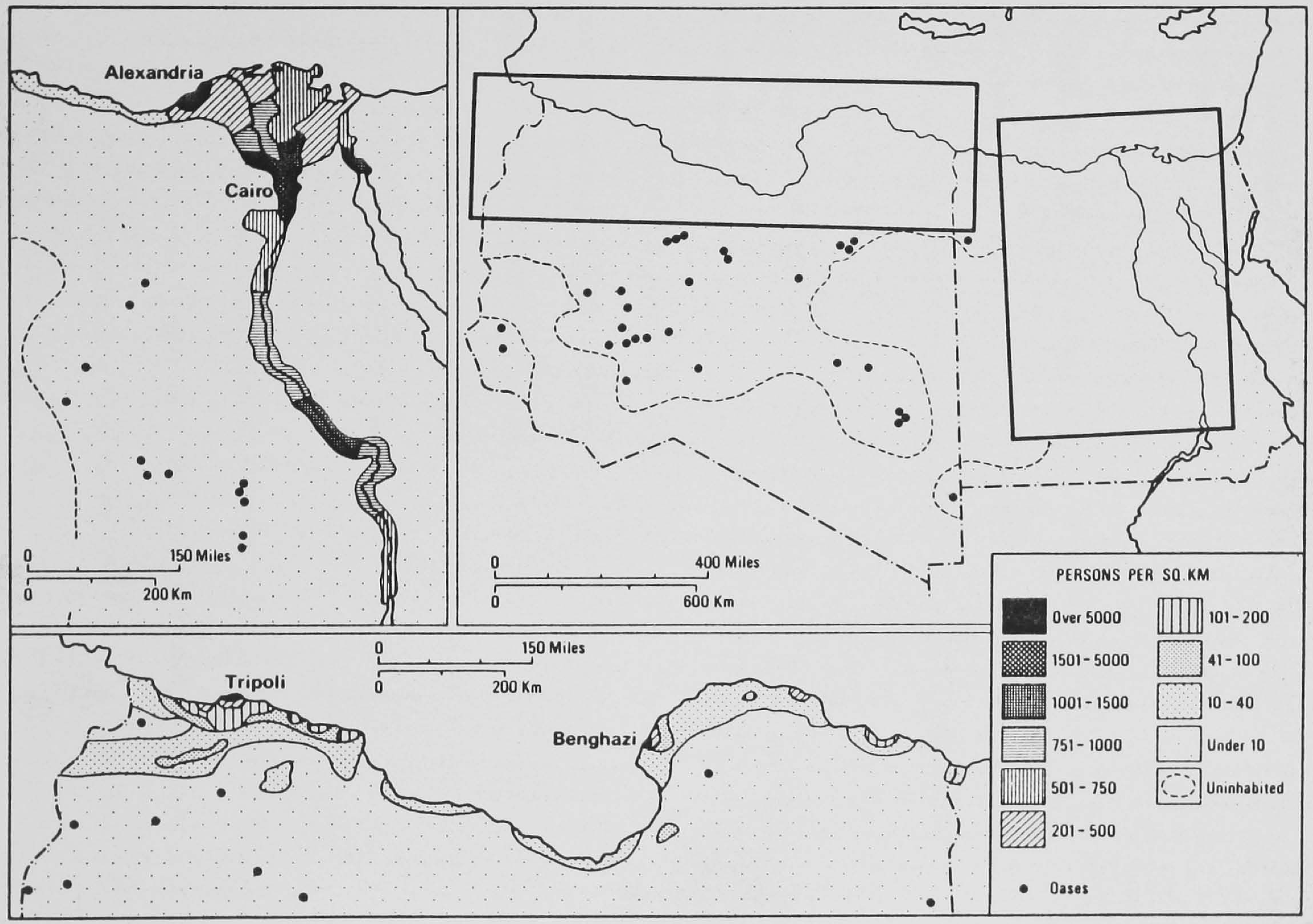
- coastal regions;
- regions of high relief;
- irrigated lands of river valleys and desert oases.

Figure 3.3 illustrates that the eastern coastline of the Mediterranean Sea supports particularly high population densities. Table 3.1 shows that countries situated entirely within the Mediterranean coastal belt, have amongst the highest population densities in the Middle East. For example, Israel (212 persons per square km.) and Lebanon (317 per square km.). These countries form part of the historical "Fertile Crescent" of the Middle East.

The littoral regions of North Africa are also heavily populated. Further inland, the Atlas mountain ranges of Morocco, Algeria and Tunisia are associated with relatively high population densities, particularly when compared to the sparsely inhabited arid and semi-arid lands of the Sahara Desert to the south.

Foremost amongst the major river valleys of the Middle East, are those of the Nile (Egypt), and the Tigris and Euphrates (Iraq).

Figure 3.4 Distribution and density of population in Egypt and Libya, 1972



After Beaumont *et al.* (1976, p.186)

These have been centres of population for centuries. The Nile valley and delta are particularly heavily populated. Figure 3.4 highlights the extremely sharp contrasts in population density that exist between the irrigated lands of the Nile, and the Eastern and Western Deserts of Egypt. Under such circumstances, the population density figures given in Table 3.1 for individual countries, clearly become very misleading.

In recent years, some Middle Eastern countries have been able to overcome the restraints placed upon them by the natural environment. The result of this has been that dense concentrations of population have arisen in parts of the Middle East that provide none of the favourable physical characteristics listed above. Nowhere has this been more apparent than in the countries surrounding The Gulf. Despite the hot and arid climate found in this part of the Middle East, dense concentrations of population now exist in the region. Table 3.1 shows that some of the small Gulf States have high population densities. For example, Bahrain (643 persons per square km.) and Kuwait (107 per square km.).

Such accumulations of people are a direct result of the impact that oil has had upon the Gulf region. Not only has this attracted large numbers of migrants to work in the area, but oil revenues have made it possible for the Gulf States to support unusually high population densities using artificial means. For example, by constructing desalination plants to provide water, by importing large amounts of food to support the increasing populations, and by constructing air-conditioned accommodation. Such options are clearly not available to the non-oil producing countries of the Middle East, where the contrasts in population density between "favourable" and "non-favourable" land will steadily increase in the future.

3.3.1.3 Implications of population growth for earthquake risk

The rapid growth in Middle Eastern population that has occurred in recent years, has undoubtedly served to increase the vulnerability of the region to earthquakes. Not least of all, this is because of the increased densities of population that have resulted. Clearly, the greater the density of population in areas that are exposed to the earthquake hazard, the greater the likelihood of large earthquake losses.

3.3.2 Increased urbanisation

The Middle Eastern population "explosion" of recent years has been accompanied by marked increases in urbanisation. As a result, the Middle East is now one of the most urbanised regions of the entire Third World (Clarke, 1981).

3.3.2.1 Levels of urbanisation

Attempts to establish present levels of urbanisation for individual Middle Eastern countries are fraught with difficulties. Most important of these, is the fact that there is no common definition of "urban" for the Middle East. Published national figures are not, therefore, always directly comparable. Bearing this limitation in mind, the figures produced by the United Nations and the Population Reference Bureau serve to give a general impression of the present

TABLE 3.2

Urbanisation Data for the Middle East

Country	Urban Population (%) 1977[1]	Urban Population (%) 1987[2]	% Increase in Urban Population 1977-1987	Number of Urban Areas with more than 100,000 Inhabitants (1970)[3]	Number of Urban Areas with more than 100,000 Inhabitants (1987)[4]
Algeria	52	53	34.4	5	8
Bahrain	78	81	50	0	1
Egypt	45	46	36.6	15	20
Iraq	64	68	52.6	9	8
Israel	82	90	23.3	4	11
Jordan	42	60	83.3	2	3
Kuwait	56	80	150	1	3
Lebanon	60	80	52.9	2	2
Libya	30	76	262.5	2	3
Morocco	38	43	50	8	18
Oman	5	9	150	0	1
Qatar	69	86	328.6	0	1
Saudi Arabia	21	72	568.8	3	7
Syria	46	49	52.8	5	8
Tunisia	47	53	42.9	1	2
U.A.E.	52	81	1000	0	4
Yemen A.R.	9	15	100	1	1
Yemen P.D.R.	33	40	66.7	1	1
Middle East	45	53	8.3	59	102

Sources of data: (1) Population Reference Bureau Inc.(1977) World Population Data Sheet, Washington (USA):P.R.B.
(2) Population Reference Bureau Inc.(1987) World Population Data Sheet, 25th ed., Washington (USA):P.R.B.
(3) Beaumont et al.(1976) - Table 6.2, p.205.
(4) United Nations (1987) Demographic Yearbook 1985, 37th Issue, New York: U.N., 1099pp.-Table 8.

levels of urbanisation in the region.

The rate of increase of urban population in the Middle East has shown almost unchecked acceleration throughout the twentieth century. In 1900, the overall level of urban population in the region was probably under 10% (Beaumont et al., 1976). By 1950 it had risen to around 25%, and by 1977 was 45%. Table 3.2 shows that today, more than half (53%) of the total population of the Middle East is classed as urban.

Figure 3.2 shows that during the past 10 years, phenomenal rates of urban growth have occurred in parts of the Middle East. Important oil producing countries like Kuwait, Libya, Oman, Qatar, Saudi Arabia and the United Arab Emirates (U.A.E.), have all experienced increases in urban population in excess of 100% (see Table 3.2). The largest relative increase was observed in the U.A.E., where the urban population in 1987 represented a 1000% increase on that of 1977. Massive urbanisation of this type is undoubtedly the direct result of large revenues derived from oil. This has permitted the construction of new "oil-cities". These have served to draw large numbers of people away from rural areas, as well as to attract abundant immigrant labour.

As was the case with population density, levels of urbanisation within the Middle East vary quite considerably from one country to another. For example, only 9% of the population of Oman is classed as urban, despite recent increases. Low percentage urban populations also exist in the Yemen Arab Republic (15%), and in the Yemen Peoples Democratic Republic (40%).

TABLE 3.3

Urban Primacy in the Middle East

Country	Largest City[1]	Population of City (year of census or estimate (E))[1]	% of Urban Population Living in Largest City (1980)[2]
Algeria	Alger	1,523,000 (1977)	12
Bahrain	Manama	108,684 (1981)	-
Egypt	Cairo	5,875,000 (1983E)	39
Iraq	Baghdad	1,984,142 (1970E)	55
Israel	Tel Aviv-Yafo	1,555,427*(1983)	35
Jordan	Amman	812,500 (1985E)	37
Kuwait	Hawalli	130,565 (1975)	30
Lebanon	Beirut	938,940*(1970)	79
Libya	Tripoli	551,477 (1973)	64
Morocco	Casablanca	1,371,330 (1971)	26
Oman	Muscat	7,000 (1979E)+	-
Qatar	Doha	90,000 (1979E)+	-
Saudi Arabia	Riyadh	666,840 (1974)	18
Syria	Damascus	1,196,710 (1985E)	33
Tunisia	Tunis	596,654 (1984)	30
U.A.E.	Dubai	265,702 (1980)	-
Yemen A.R.	San'a	140,339 (1975E)	25
Yemen P.D.R.	Aden	251,590 (1977E)	49
U.K.	London	6,696,008 (1981)	20

* Population of urban agglomeration
\- No data available

\+ Source of data = Purnell's Pocket Picture Atlas (1979), Maidenhead: Purnell Books, 160pp.

Sources of data: 1. United Nations (1987) Demographic Yearbook 1985, 37th Issue, New York:U.N., 1099pp. - Table 8
2. The World Bank (1987) World Development Report 1987, New York:Oxford Uni. Press, 285pp. - Table 33

On the other hand, two-thirds of Middle Eastern countries now have majority urban populations. Small states like Israel and Qatar, with urban populations of 90% and 86% respectively, are amongst the most highly urbanised countries in the world.

3.3.2.2 The growth of cities

As a result of the rapid urbanisation of the Middle East, there has been a remarkable increase in the number of large towns in the region (i.e. those with populations greater than 100,000). At the turn of the century there were probably no more than 4 towns of this size in North Africa, and fewer than a dozen in south-west Asia (Beaumont _et al_., 1976). By 1970, 59 cities in the Middle East had populations greater than 100,000, and by 1987 the total had risen to 102 (see Table 3.2). These cities have resulted both from the expansion of existing settlements, and the creation of new ones. They show a similar pattern of distribution to that observed for population density (see Section 3.3.1.2). The densest networks of towns lie along the eastern Mediterranean shoreline, the Nile valley and delta, the floodplains of the Euphrates and Tigris rivers, and along the Mediterranean coastline of North Africa.

As more and more people become concentrated in urban areas that are exposed to the earthquake threat, the likelihood of large earthquake losses increases. This problem is made worse in many Middle Eastern countries, by a tendency towards over-concentration of urban population in selected cities. Table 3.3 lists data for the most populous city in each Middle Eastern country. It highlights the fact that in 1980, the proportion of urban populations living in largest

TABLE 3.4

Cities of the Middle East with over One Million Inhabitants

Country	City	Population of City (date of census or estimate (E))[1]	% of Country's Population in the City (year)[2]
Algeria	Alger	1,740,461 (1977)*	8.56 (1977)
Egypt	Alexandria	2,705,000 (1983E)	5.89 (1983)
	Cairo	5,875,000 (1983E)	12.80 (1983)
	Giza	1,640,000 (1983E)	3.57 (1983)
Morocco	Casablanca	2,408,600 (1981E)*	11.05 (1983)
Iraq	Baghdad	2,736,791 (1980E)+	20.73 (1980)
Israel	Tel Aviv-Yafo	1,555,427 (1983)*	37.94 (1983)
Lebanon	Beirut	938,940 (1970)*	44.16 (1970)
Syria	Aleppo	1,145,117 (1985E)	10.80 (1985)
	Damascus	1,196,710 (1985E)	11.29 (1985)

* Population of Urban agglomeration
+ Estimate by Ali (1985) - Table 4.9; p.137.

Sources of data:
1. United Nations (1987), Demographic Yearbook 1985, 37th Issue, New York: U.N., 1099pp. - Table 8.

2. Based upon mid-year population estimates from various issues of the World Population Data Sheet, produced by the Population Reference Bureau Inc., Washington (U.S.A.): P.R.B.

Note: Beirut is listed in the table above because it had almost one million inhabitants in 1970 - more recent data are unfortunately not available for the city.

cities exceeded 20% in all but two of the countries for which data are available. The exceptions were Algeria (12%) and Saudi Arabia (18%). Over-concentration of urban population was most severe in the Lebanon, where 79% of urban dwellers lived in Beirut. High urban concentrations were also recorded for Tripoli (64%), Baghdad (55%), Aden (49%) and Cairo (39%). By way of comparison, London accommodated only 20% of the total urban population of the United Kingdom in 1980.

The problem of over-concentration of population in selected cities is emphasised by Table 3.4. This lists all the "million-plus" cities in the region (according to the most recent population data available). The marked polarisation that is taking place in Middle Eastern populations is demonstrated by the fact that 21% of the total population of Iraq live in Baghdad. In Israel, 38% of the population live in the Tel Aviv-Yafo metropolitan area.

3.3.2.3 Implications of increased urbanisation for earthquake risk

The phenomenal rates of urbanisation observed in the Middle East in recent years have served to concentrate a larger proportion of the region's population in urban areas, and hence to create relatively localised peaks in population density. Added to this, there has been a tendency for urban populations to become increasingly polarised, due to the over-concentration of urban dwellers in one or two large cities or city regions within countries.

Such concentrations of population are obviously of great concern, particularly when they are situated in parts of the Middle East that

TABLE 3.5

G.N.P. Data for the Middle East

Country	G.N.P. per Capita (U.S. Dollars, 1985)	Average Annual Growth Rate of G.N.P. per Capita, 1965-1985 (%)
Algeria	2,550	3.6
Bahrain	-	-
Egypt	610	3.1
Iraq	-	-
Israel	4,990	2.5
Jordan	1,560	5.8
Kuwait	14,480	-0.3
Lebanon	-	-
Libya	7,170	-1.3
Morocco	560	2.2
Oman	6,730	5.7
Qatar	-	-
Saudi Arabia	8,850	5.3
Syria	1,570	4.0
Tunisia	1,190	4.0
U.A.E.	19,270	-
Yemen A.R.	530	5.3
Yemen P.D.R.	530	-
Average of Industrial Market Economies	11,810	2.4
U.K.	8,460	1.6

\- No data listed by The World Bank

Source of data: The World Bank (1987), World Development Report 1987, New York: Oxford University Press, 285pp. - Table 1.

are exposed to the earthquake threat. They have undoubtedly served to increase the vulnerability of parts of the region to large earthquake loss.

3.3.3 Economic development

Ali (1984) has conducted a very thorough and comprehensive examination of the economic development of the Arab world during the period 1970-1984. His study encompasses all the countries included in the present study, with the obvious exception of Israel. Much of the discussion in this section is therefore based upon Ali's work.

Table 3.5 shows that during the period 1965-1985, the economies of most Middle Eastern countries experienced considerable growth. Many of the countries in fact achieved a much faster rate of economic growth than the heavily industrialised nations of the world.

During the period 1970-1980, economic growth in the Middle East was generally greatest in the oil producing countries (Ali, 1984). Export earnings from oil increased markedly during this decade, particularly after the oil embargo of 1973. These earnings provided the oil states with large amounts of finance for investment and development.

Reduced levels of oil exports from 1983 onwards, combined with lower oil prices, have served to bring to a temporary halt the economic growth of some of the oil-producing states. It is for this reason that Libya and Kuwait show negative growth values in Table 3.5. Despite this, the 1985 GNP per capita data listed in the table serve to demonstrate the relative prosperity of the Middle East as a region. Indeed, the GNP per capita of the United Arab Emirates (U.A.E.) was higher than in any other country of the world during this particular year.

In many Middle Eastern countries, the economic development of recent years has been associated with increased industrialisation (the industrial sector is often regarded as a development priority). This has resulted in considerable growth in industrial and manufacturing output throughout the region. Ali (1984) has shown that during the period 1970-1980, the Arab countries achieved higher growth rates in industry and manufacturing than the heavily industrialised countries of the world. The oil-producing states in particular, have embarked on ambitious economic development programmes funded by oil revenues. They have invested large sums of money in the heavy industry sector, and many large industrial projects are now in operation, or are under construction.

Industrial expansion has not been limited to the oil-based economies of the Middle East. The non-oil states have also initiated rather ambitious industrial programmes, all of which require a considerable amount of capital investment.

The extensive development programmes of Middle Eastern countries have caused a dramatic growth in construction markets. They have also resulted in the rapid development of more elaborate communication networks (e.g. road, rail, air, telecommunications and oil/gas pipelines). For example, in 1981 Saudi Arabia introduced the world's first metropolitan telephone system to be entirely controlled by computers (Ali, 1984).

3.3.3.1 Future economic prospects in the Middle East

The recent fall in oil prices has not had a particularly serious effect upon the economic development of the Middle East. The size of the oil resources in the region is such, that the Middle East as a whole will continue to earn considerable oil revenues until the middle of the next century (Ali, 1984). These will undoubtedly provide sufficient finance to ensure that future industrial and commercial development in the region continues at a rapid pace.

3.3.3.2 Implications of economic development for earthquake risk

The recent economic development of the Middle East has undoubtedly served to increase the vulnerability of the region to large financial earthquake losses. There are two main reasons for this:

a) Across the region there have been dramatic escalations in the capital assets of urban areas. Large investment and development programmes have greatly increased the value of risks exposed to earthquake hazard (e.g. oil refineries and industrial plants);

b) Economic advancement has led to the introduction of highly sensitive (easily damaged), capital intensive technologies to the region (e.g. computers and telecommunication systems).

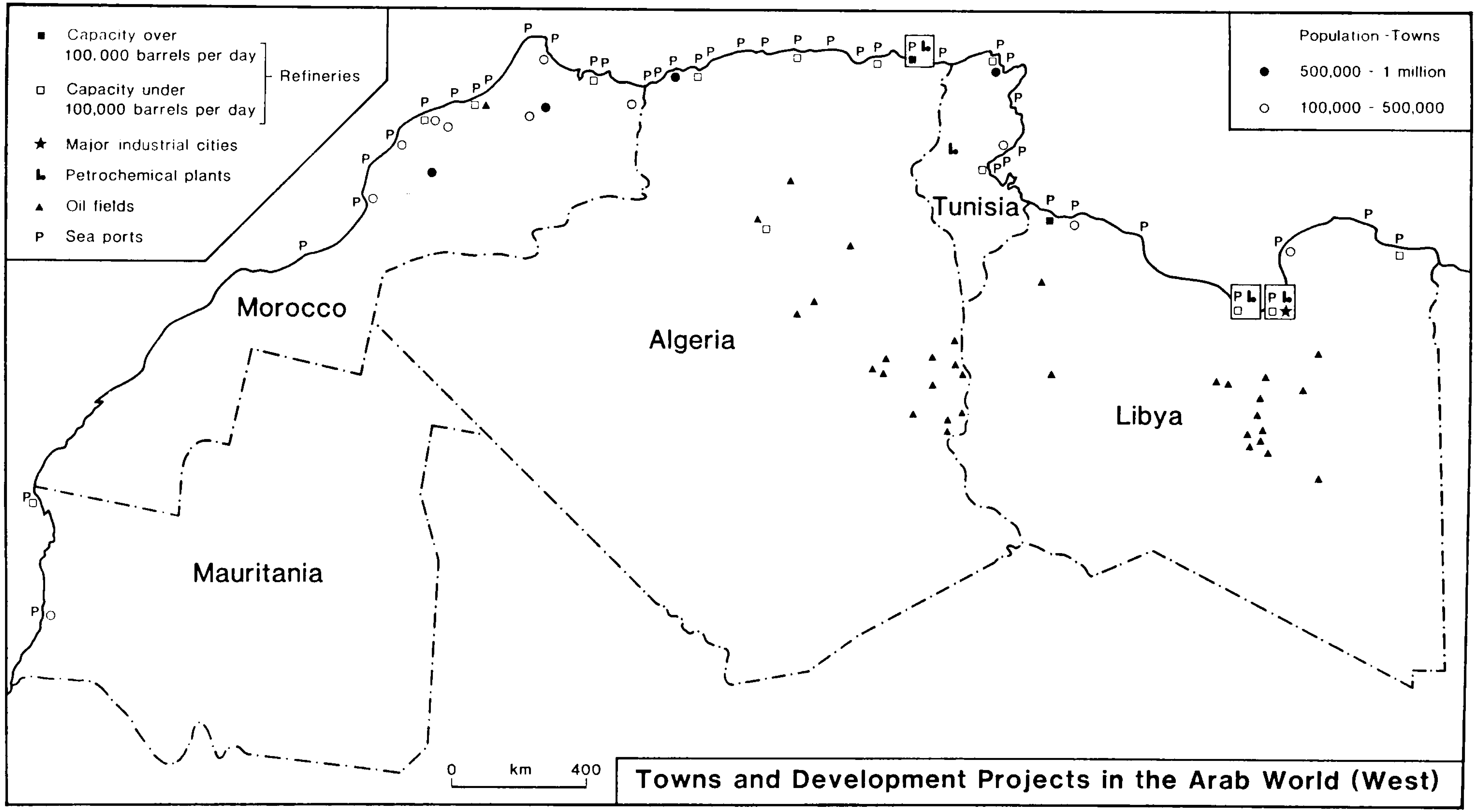
3.4 SUMMARY OF THE PROBLEM

The Middle East, as defined in this study, comprises 18 countries. These show considerable variation in geographical area, total population, level of urbanisation and stage of economic development. The sharpest distinction occurs between the oil-producing countries and the non-oil producers.

The Middle East as a whole has experienced extremely rapid population growth in recent years. The net result of this has been to increase the overall density of population across the region. Increased population densities mean that future earthquakes are likely to exact an increasing toll in human lives. This problem is heightened by the fact that the distribution of people is by no means uniform. High densities of population occur in areas where environmental conditions (climatic and economic) are favourable for settlement. Elsewhere, large tracts of arid and semi-arid land remain largely uninhabited.

In addition to natural population increase, many countries in the Middle East have experienced phenomenal rates of urbanisation during the past 20 years. More and more people have become concentrated in urban areas, and this has served to increase still further the uneven distribution of population. Of particular concern is the polarisation of the urban population of individual countries into one or two large cities or city regions. The dangers of this were made only too apparent by the Mexican earthquake disaster (see Sections 2.2 and 2.13.5).

Figure 3.5



Modified from Ali (1985, p.350)

Such massive concentrations of people and urban infrastructure have obviously caused a dramatic escalation in the risk of catastrophic earthquake loss. Furthermore, due to the increased pressure on space in urban agglomerations of this type, an increasing amount of development is taking place in marginal areas (e.g. on steep slopes and reclaimed land). Such areas, avoided by populations of the past, often provide unfavourable environmental conditions that serve to increase vulnerability to natural hazards like earthquakes.

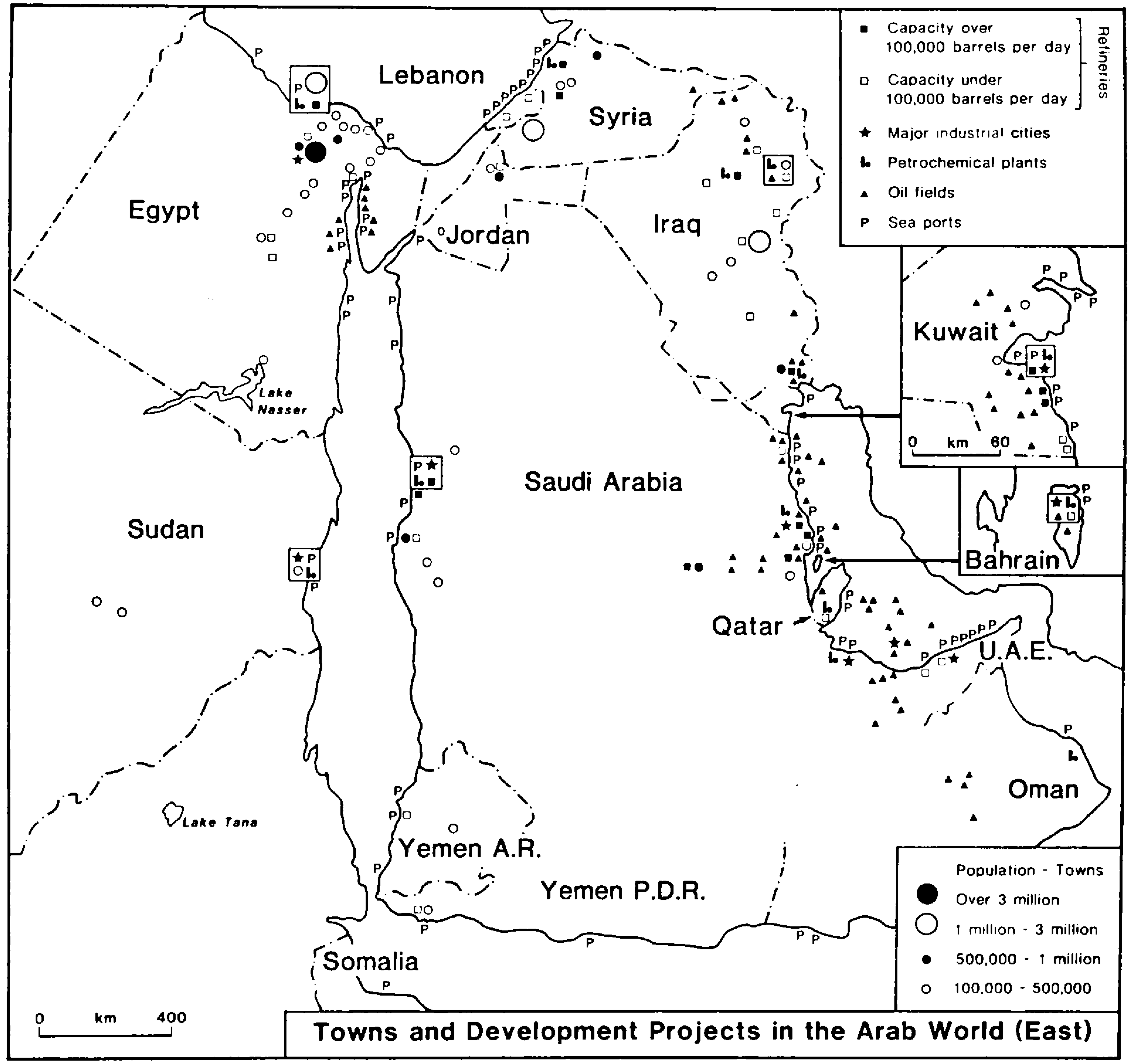
In contrast to many other parts of the world, the last 20 years have seen rapid economic growth in the Middle East. This has been most apparent in the oil-producing states, where ambitious economic development programmes are the result of greatly increased oil export earnings. Across the region, increased wealth has been reflected in a growth of investment in industry, manufacturing, construction and communications. Once again, however, much of this investment has been over-concentrated in specific areas. There has consequently been a dramatic rise in the vulnerability of the Middle East to catastrophic economic earthquake losses.

It can therefore be concluded that <u>over-concentration</u> is the primary reason for escalating earthquake risk in the Middle East. This over-concentration has been in terms of:

- population growth;
- urban growth;
- economic development and investment (e.g. in industrialisation).

Figures 3.5 and 3.6 provide an excellent summary of the situation

Figure 3.6



Modified from Ali (1985, p.348)

(data on Israel are excluded from Figure 3.6). Development in the Middle East has been concentrated in particular areas. For example, the Nile delta, the Mediterranean and Red Sea coastlines, the Nile, Tigris and Euphrates river valleys and the Gulf region. Such concentrations are of great concern, particularly when they are situated in parts of the region that are exposed to earthquake hazard. As more and more development is channelled into these areas in the future, catastrophic losses (both in human and economic terms) will become increasingly likely.

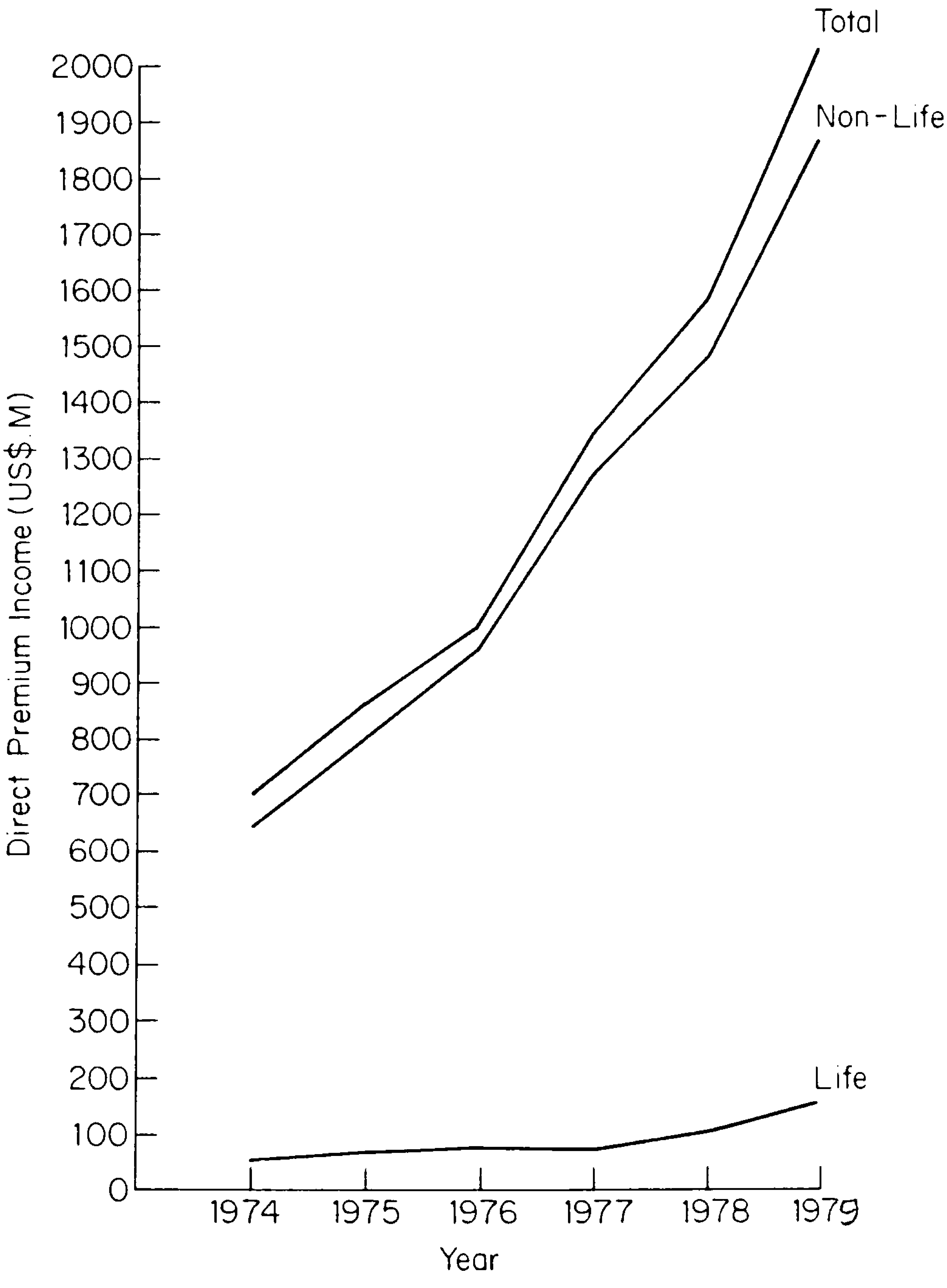
3.5 THE IMPACT OF MIDDLE EASTERN DEVELOPMENT ON THE INSURANCE INDUSTRY

In addition to his work on the economic development of the Arab countries, Ali (1984) has conducted a detailed survey of the development of the insurance industry in the Arab region. For reasons already given in Section 3.3.3, his work will form the basis for much of the discussion in this section.

The rapid economic growth of the Middle East has had important repercussions for the insurance industry. It has resulted in a large increase in the demand for all classes of insurance, and this demand can be expected to continue to grow in the future. The manner in which the development has occurred, particularly in the oil-producing states of the region, has meant that a large proportion of the demand for non-life insurance has been concentrated on large individual risks (e.g. oil installations and refineries, oil pipelines, heavy industrial plants, super tankers and major construction projects). The implications of this for the

Figure 3.7

Arab direct premium income for the period 1974–79



After Ali (1985, p.13)

insurance industry will be discussed below.

3.5.1 Increased insurance business in the Middle East

Insurance markets in the Middle East are still in their infancy. As a result of the rapid economic development of the region during the past two decades, however, there has been a large increase in the demand for various classes of insurance.

Ali (1984) has shown that prior to 1970, the premium income of all Arab insurance markets was very small indeed. Since then, insurance business in these markets has grown rapidly. The recent rates of increase in insurance expenditure in Middle Eastern countries, rank foremost amongst many of the developing and developed countries of the world.

Figure 3.7 shows the rapid growth in the premium volume of the Arab insurance markets that took place during the second half of the 1970's. During this period, their total insurance premium volume nearly tripled, from US$ 701.5 million in 1974, to US$ 2037.4 million in 1979. This amounts to an average annual growth rate of 31.5%, although part of this increase was due to inflation. Taking into account inflation rates, the region clearly experienced substantial real growth of premium volume during the 1970's (Ali, 1984). This was despite the fact that during the same time period, world-wide real premium income declined (due to global recession in 1974-75 and 1979).

The potential for future growth in Middle Eastern insurance markets is very great indeed. This is particularly the case in the Arab countries, where the development of some markets has been hindered by the fact that many Moslems still regard insurance as contrary to the tenets of their faith (Ali, 1984).

3.5.2 Insurance density and the composition of insurance portfolios

In keeping with the imbalances in economic investment, insurance markets in Middle Eastern countries are often restricted to the major cities. As a consequence of this, the density of insurance business varies across the region. The uneven distribution of insurance density is heightened by the problems of over-concentration discussed in Section 3.4.

In addition to an uneven distribution of business, Middle Eastern insurers are faced with severe imbalances in their insurance portfolios. The rapid industrialisation that has taken place in the region has led to the construction of large risks with substantial insurance values. For example, insured values of hundreds of millions of U.S. dollars have become common for petrochemical plants in many Middle Eastern countries.

Unfortunately, the sharp rise in demand for large risks business has not been offset by a corresponding increase in medium sized commercial business and life insurance. Portfolios have therefore become dominated by high exposures and complex risks. This imbalance is demonstrated by the fact that during the period 1974-79, non-life premium income accounted for more than 90% of total insurance business in most Arab countries (see Figure 3.7). The demand for life insurance in Arab countries remains low, and is the least developed of all the insurance classes. This is mainly due to relatively low standards of living, and the cultural and religious influences mentioned in Section 3.5.1.

As a result of the imbalances between loss potentials and direct premiums, strict limitations have been placed upon the retention capacity available in the Middle Eastern insurance markets. This has obliged many Middle Eastern insurers to reinsure themselves heavily abroad. In addition, the rapid growth in the number and size of large risks has led to problems of risk assessment, premium rating and claims settlement (Ali, 1984).

3.5.3 Future development of Middle Eastern insurance and reinsurance business

Despite recent minor set-backs in the economic development of some Middle Eastern countries (see Section 3.3.3), and problems of political instability, it is beyond doubt that rapid economic development will continue in the region (Ali, 1984). As a result, insurance and reinsurance markets in the Middle East should continue to grow at relatively fast rates. In view of this (and the problems outlined in the sub-sections above), it is essential for insurers and reinsurers operating in the region to attain a better understanding of the exposure of their portfolios to natural hazards like earthquakes.

TABLE 3.6

Some Major Twentieth Century Earthquakes in the Middle East

DATE	LOCATION	MAGNITUDE	FATALITIES	ECONOMIC LOSS (US $ millions)
1982 Dec 13	Severely affected the Dhamar district of northern Yemen Arab Republic	5.7	1,900	218
1980 Oct 10	Total destruction of El Asnam, Algeria	7.2	2,590	2,200
1969 Mar 31	Widespread damage in Egypt from a shock close to the Shadwan Islands in the Red Sea	7.0	2	-
1969 Feb 28	Widespread damage in Morocco caused by an offshore earthquake	8.0	11	-
1963 Feb 21	Locally damaging shock at Al Marj, Libya	5.3	300	5
1960 Feb 29	Total destruction of Agadir, Morocco	5.9	12,000	120
1960 Feb 21	Locally damaging at M'sila, Algeria	5.6	57	-
1957 Feb 20	Locally damaging in S.W. Tunisia	5.6	13	-
1956 Mar 16	Locally destructive in the Litani Valley, Lebanon. Especially affected Chouf	6.0	136	-
1955 Sep 12	Localised damage in the Nile Delta caused by an offshore shock	6.1	18	-
1954 Sep 9	Total destruction of Orleansville (El Asnam) in Algeria	6.7	1,243	6
1946 Jul 27	A series of shocks causing damage in Penjween, Iraq	5.4	6	-
1946 Feb 12	Locally destructive south of Bougie, Algeria	5.7	264	-
1941 Jan-Feb	A series of shocks affecting northern Yemen Arab Republic	5.2 - 5.8	1,200	-
1927 Jul 11	Destructive in the Damiya region of Jordan, and the West Bank	6.25	342	-
1926 Jun 26	Widespread damage in Lower Egypt caused by an offshore shock	7.7	12	-
1917 Jul 15	Locally damaging in the region of Tursaq, Iraq	5.7	-	-
1909 Jan 21	Locally damaging in the Tetouan region, Morocco	6.2	100	-

- Figures unobtainable due to lack of data

Main sources of data: Cidlinsky and Rouhban (1983); Gutenberg and Richter (1965); Karnik (1969); Munich Re. (1978); Riad and Meyers (1985); Rothe (1969); Swiss Re. (1978)

The data presented in this table are drawn from a variety of sources, and are not uniformly standardised. Care should therefore be taken in interpreting them.

3.6 THE SIGNIFICANCE OF EARTHQUAKE HAZARD TO INSURANCE AND REINSURANCE COMPANIES OPERATING IN THE MIDDLE EAST

As mentioned in Section 1.1, Ali (1984; 1985) has shown that many of the expanding cities in the Middle East, and much of the recent economic development, are located in areas exposed to earthquake hazard (see Table 1.1). The escalating earthquake risk in these areas is something that has become of major concern to both insurers and reinsurers. This concern has been heightened by the rapid growth in the number and size of large insurance risks throughout the region, and the imbalances in insurance portfolios referred to in Section 3.5.2.

Table 3.6 lists major 20th century earthquakes in the Middle East. The escalation in earthquake risk is illustrated by comparing the economic loss caused by the 1980 earthquake at El Asnam (US$ 2,200 million), with that experienced as a result of a similar earthquake in 1954 (US$ 6 million). Insurers and reinsurers obviously need to take urgent steps to control their vulnerability to earthquake-inflicted losses in the region. Such steps must be based upon reliable assessments of the exposure of Middle Eastern countries to earthquake hazard. These assessments should be designed to meet the specialist requirements of insurers and reinsurers.

The Munich Re. (1976) have described a procedure of assessing and controlling earthquake risk for insurance purposes. This procedure is based upon the identification of 3 types of zone:

a) Earthquake exposure zones;

b) Earthquake accumulation assessment zones;

c) Earthquake loss accumulation zones.

Earthquake exposure zones show the spatial distribution and severity of earthquake hazard. The delineation of such zones requires the specialist knowledge of the earth-scientist. In contrast, insurers and reinsurers are best qualified to define earthquake loss accumulation zones. This is because such zones should (in part) be based upon data concerning the composition of insurance portfolios. The purpose of this study, therefore, is to provide information needed to define zones of type (a) in the Middle East. The study will conclude by showing how these data can be incorporated in insurance and reinsurance procedures for assessing and controlling earthquake risk, that use zones of types (b) and (c).

3.7 METHOD OF ANALYSIS OF EARTHQUAKE HAZARD IN THE MIDDLE EAST

In Chapter 2 the "anatomy" of an earthquake disaster was described. The findings of the 1985 Mexican earthquake have highlighted several important factors that need to be taken into consideration when attempting to assess earthquake hazard in a region. These are summarised in Section 2.13, and include:

a) Analysis of tectonic setting;

b) The use of historical and 20th century earthquake data to determine the rates of activity of tectonic zones (including the identification of seismic gaps);

c) The importance of subsoil conditions in controlling the severity of ground motion experienced during earthquakes.

These lessons have been incorporated in the analysis of earthquake hazard in the Middle East, the first part of which (a regional examination) is presented in Chapters 4 to 6. This analyses the tectonic setting of the region. Tectonics are then related to historical and 20th century earthquake data in order to delineate the extent of the earthquake hazard. On the basis of this, areas that are particularly susceptible to earthquake-induced losses are identified.

The second part of the analysis (Chapters 7 and 8) is concerned with describing a technique of earthquake hazard zonation that has been developed for application in the hazardous parts of the region. This is used to zone Israel, and forms the basis of a comprehensive (insurance-oriented) analysis of earthquake hazard and risk in the country.

3.8 CONCLUSIONS

The risk of large earthquake losses in the Middle East is increasing at a rapid rate. The is due to a number of reasons, the most important of which are:

- the growth of population, which has resulted in higher population densities;

- rapid industrialisation, which has served to concentrate more and more people in urban areas. Consequent overcrowding in cities has led to the development of marginal areas that are often more exposed to the earthquake hazard;

- the rapid economic development of the region. This has increased capital assets in urban areas, and raised the value of property exposed to the earthquake threat.

At the same time, insurers and reinsurers operating in the Middle East have become more vulnerable to catastrophic loss. This is partly because of the increase in demand for all classes of insurance that has accompanied economic development. Of greater concern, however, is the uneven distribution and unbalanced nature of Middle Eastern insurance business. Insurance portfolios in the region have become characterised by high exposures and complex risks.

In view of this, it has become imperative for insurers and reinsurers to take urgent steps to control their vulnerability to earthquake-inflicted losses in the Middle East. Such steps need to be based upon reliable assessments of the exposure of Middle Eastern countries to earthquake hazard. The purpose of the remainder of this study is to describe such an assessment, and to show how the risk of future large earthquake losses in the region can be reduced.

MIDDLE EASTERN HAZARD ANALYSIS (PART A) - A REGIONAL EXAMINATION

CHAPTER 4. TECTONICS AND TWENTIETH CENTURY SEISMICITY OF THE MIDDLE EAST

4.1 INTRODUCTION

Almost 99% of all earthquakes are associated with plate boundary interactions (Lomnitz and Singh, 1976). The identification of active plate boundaries therefore serves as a primary step in the delineation of earthquake hazard.

The size (magnitude), depth, distribution and rate of earthquake activity along a plate boundary, varies according to the nature of the plate interaction that is taking place. Since these four factors exert a strong influence on the frequency and severity of earthquake shaking experienced at the surface, analysis of plate interactions should also form the basis of any attempt to assess earthquake hazard in a region.

Such an approach to earthquake hazard assessment is referred to as seismotectonic analysis. It is best conducted using 20th century earthquake data, because these have to their advantage the fact that they have been recorded instrumentally. The data therefore contain relatively accurate information concerning the location, depth and size of earthquakes.

The purpose of this chapter is to present a preliminary assessment of earthquake hazard in the Middle East, by analysing the seismotectonic setting of the region. 20th century earthquake activity in the region is summarised, and used to delineate major tectonic zones. The nature of the plate interactions taking place along these zones is discussed, as are the types of seismic activity associated with them. The chapter concludes with an analysis of the advantages and disadvantages of using 20th century seismic data to assess earthquake hazard.

4.2 MIDDLE EASTERN TECTONICS - A GLOBAL PERSPECTIVE

The two most active tectonic belts in the world are:

a) The circum-Pacific belt;

b) The Mediterranean and trans-Asiatic belt.

Lomnitz and Singh (1976) have shown that approximately 75% of all earthquakes occur along the tectonic zones that surround the Pacific plate and its adjoining minor plates. A detailed account of a small part of the circum-Pacific seismic belt was given in Section 2.3.

The Mediterranean and trans-Asiatic seismic belt accounts for approximately 22% of global earthquake activity (Lomnitz and Singh, 1976). It extends from the Azores, along the Alpine mountain chains of southern Europe and North Africa, to Asia Minor and the Caucasus. The belt then continues eastwards through Iran, Pakistan, the Pamirs, the Himalayas, Tibet and China. Some of the largest shallow-focus earthquakes ever recorded have been associated with the Mediterranean/trans-Asiatic seismic belt. It is responsible for much of the earthquake activity recorded in the Middle Eastern region.

4.3 TWENTIETH CENTURY EARTHQUAKE DATA FOR THE MIDDLE EAST

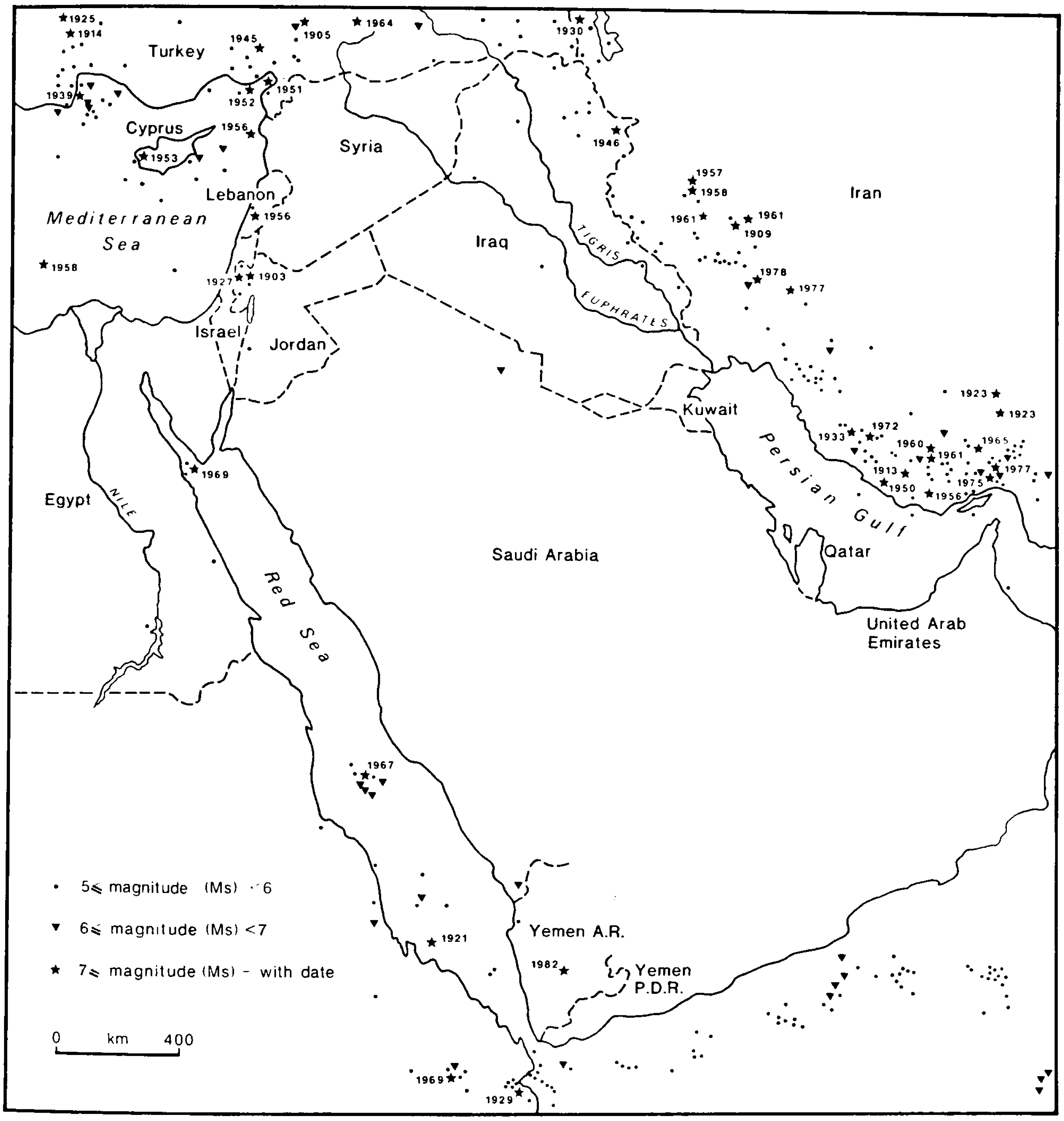
Twentieth century earthquake data for the Middle East are relatively easily obtained from the bulletins of the various seismological stations that operate in the region (e.g. the Helwan Observatory, Cairo). Earthquake listings printed by the National Geophysical Data Center (NGDC) of the U.S.A., the United States Coast and Geodetic Survey, the British Geological Survey (Edinburgh) and the International Seismological Centre also provide a wealth of data concerning recent seismic activity in the region. Riad and Meyers (1985) have produced a comprehensive catalogue of significant earthquake activity (for the years 1900-1983) which covers most of the region.

4.4 SEISMOTECTONIC ANALYSIS OF THE MIDDLE EAST (Eastern part)

For ease of discussion, the description of Middle Eastern tectonics and recent seismicity has been subdivided into two sections. This section will refer to the eastern part of the study area, whereas Section 4.5 will refer to the western part (see Figure 3.1 for the countries concerned). Such a subdivision of the discussion is justifiable on the grounds that there are important tectonic differences between the two areas. These will be highlighted in this section, and the next.

Figure 4.1

Earthquake activity in the eastern area, 1900–1983



Source of data: Riad *et al.* (1985)

The spatial distribution of 20th century earthquake activity in the eastern part of the study area is shown in Figure 4.1. Only earthquakes of magnitudes greater than 5.0 are shown on the map, because it is assumed that such events cause ground motion sufficiently severe to be potentially damaging to structures. Earthquakes of magnitudes less than 5.0 are unlikely to be damaging, due to the very short duration of shaking and moderate ground acceleration associated with this size of event (Kebeasy, 1981).

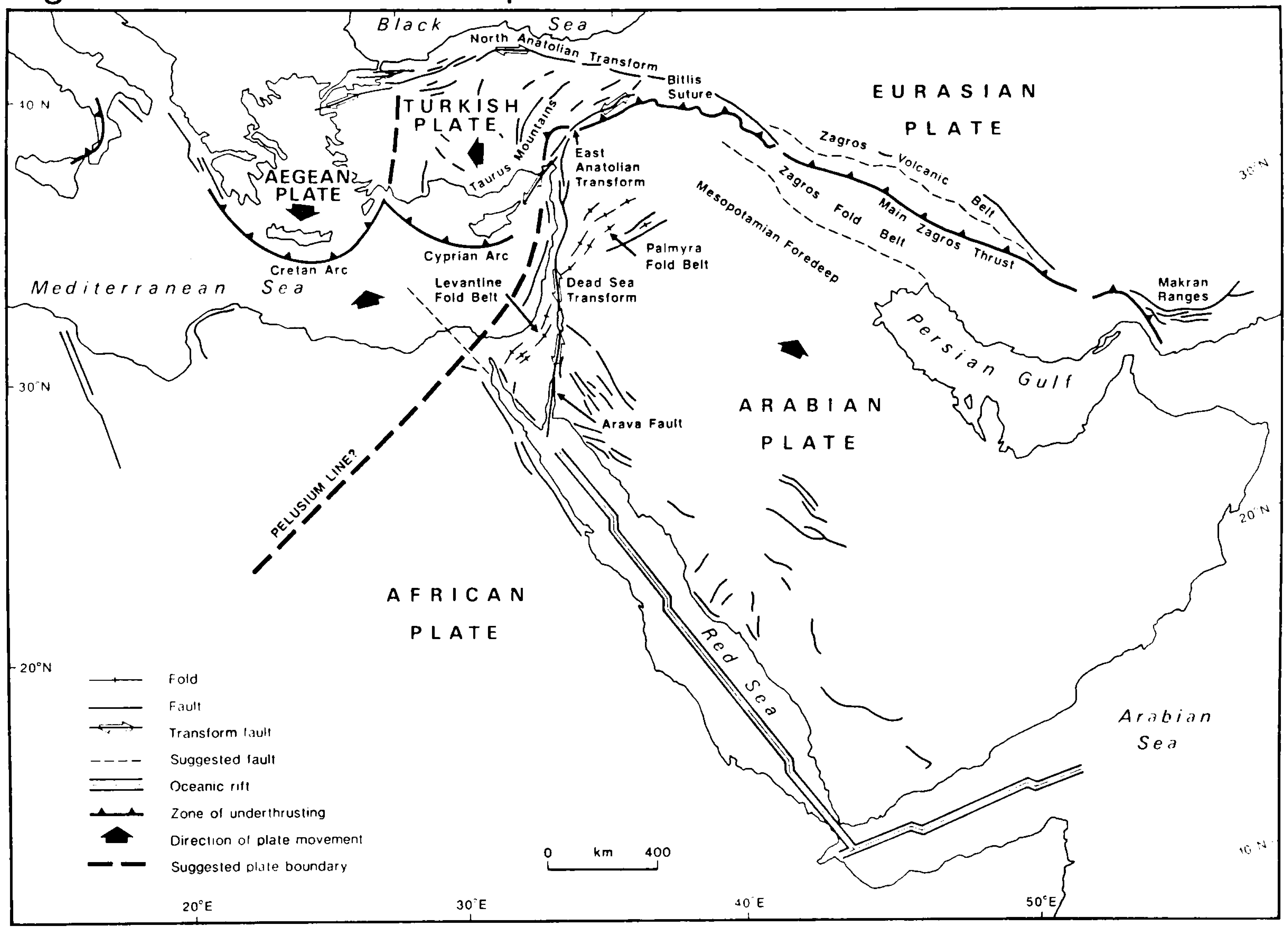
The earthquake epicentres shown in Figure 4.1, serve to define the boundaries of the major tectonic units in this part of the Middle East. These units are shown in Figure 4.2, and fall into four groups:

a) The Red Sea and Gulf of Aden. Both these tectonic structures are zones of active sea-floor spreading, along which the Arabian plate is gradually moving away from the African plate;

b) The Dead Sea transform fault system. This extends from the Gulf of Aqaba, northwards through Israel, Jordan, Lebanon and Syria, to terminate at the Syria/Turkey border. It is frequently referred to as the Levant fracture zone (the Levant = the eastern Mediterranean with its islands and neighbouring countries). Along the Dead Sea transform, the Arabian plate (to the east), is moving north relative to the plates to the west. This movement transforms the spreading motion of the Red Sea into continental collision in northern Turkey and Iraq;

c) The Zagros mountain belt of north-eastern Iraq. This belt marks

Figure 4.2 Tectonic map of the eastern area



Based upon maps by: Adams and Barazangi (1984, pp.1016 and 1018), Mckenzie (1970, p.242) and Sengor (1979, p.279) the zone of collision between the Arabian and Eurasian plates. In the west it is continuous with the Anatolian fault systems and Taurus mountains of Turkey;

d) The eastern Mediterranean basin. This is a particularly active seismic area. Within the basin, there is a complicated interaction between slabs of oceanic and continental crust. Many aspects of the tectonics of the Mediterranean sea-floor are still poorly understood.

The remainder of the area (notably the interior of the Arabian plate) has been largely aseismic this century.

4.4.1 The Red Sea and Gulf of Aden region

Drake and Girdler (1964) were amongst the first to suggest that the Gulf of Aden and Red Sea developed in response to a relative displacement of Arabia with respect to the African continent. This motion has incorporated a minor component of rotation of the Arabian plate relative to Africa.

The exact age of the Red Sea is uncertain. Adams and Barazangi (1984) suggest that the Red Sea first developed as a trough during the Oligocene and Miocene. Similarly, Le Pichon and Francheteau (1978) suggest that separation of the African and Arabian plates commenced in the early Miocene, following a phase of uplift and faulting during the Oligocene-Miocene. In contrast, Girdler and Styles (1974) propose a two-stage model of sea-floor spreading in the Red Sea. According to them, the first major rift movements took place in the Lower-Middle Eocene (50 million years ago). Following these, a major phase of sea-floor spreading occurred in the Upper Eocene and early Oligocene. There was then a long quiescent period of about 30 million years, followed by renewed activity during the Upper Miocene to Lower Pliocene (5 million years ago).

Two basic models have been proposed to account for the origin and evolution of the Red Sea and Gulf of Aden:

a) McKenzie et al. (1970) have proposed that the entire floor of the Red Sea and Gulf of Aden is made up of newly created oceanic crust. They argue that there is an abrupt change between the continental crust of the Arabian continent, and the oceanic crust of the Red Sea. Their arguments are supported by Greenwood and Anderson (1977), and Healy et al. (1982);

b) Lowell and Genik (1972), Ross and Schlee (1973) and Le Pichon and Francheteau (1978), argue that the total amount of oceanic crust in the Red Sea is very small. They suggest that oceanic crust is restricted to the presently volcanic axial trough of the sea, and that the main trough is floored by continental crust. This has been thinned by faulting and intruded by volcanics. Attenuated continental crust is therefore thought to separate the true continental crust of the Arabian plate, from the oceanic crust of the Red Sea axial trough.

Figure 4.1 shows that numerous large earthquakes have occurred along the Red Sea and Gulf of Aden during the present century. In March 1967, a sequence of earthquakes occurred in the central part of the

Red Sea rift, only 150km south-west of Jeddah. In 1969, a particularly large event occurred near to the Shadwan Islands. These are situated in the northern part of the Red Sea, at the southern end of the Gulf of Suez.

The seismicity of the Red Sea is largely restricted to a narrow linear belt (less than 50km wide) which follows the axial trough of the sea. Similarly, most of the seismic activity in the Gulf of Aden is associated with the axial zone. The axial rifts of both areas are zones of shallow seismic activity (<70km deep), with earthquakes occurring in response to the formation of new crust as the African and Arabian plates are pushed apart. Active volcanism within the axial trough of the Red Sea provides further evidence of present-day rifting (Fairhead and Girdler, 1970).

Figure 4.1 shows that the northern and southern parts of the Red Sea, are currently more seismically active than the central part. All in all, seismic activity in the Red Sea is less than that in the Gulf of Aden and the Arabian Sea. This is something which has previously been noted by Drake and Girdler (1964), Sykes and Landisman (1964) and Gutenberg and Richter (1965).

4.4.2 The Dead Sea transform fault system

The rift valley of the Dead Sea transform fault system is one of the most prominent morphological features in the entire Middle East. It is an elongated depression (approximately 1,000km long) which is at its widest and deepest in the Gulf of Aqaba. The rift is bordered by normal faults and flexures, and marks the boundary between the

Arabian plate to the east and the African and Sinai plates to the west.

The fault system formed as a result of the break-up of the Arabian plate from the African plate (Adams and Barazangi, 1984). Motion along the fault is predominantly of a left-lateral type, with minor components of compression and extension. Nur and Ben-Avraham (1978) have shown that to the east of the rift, left-lateral motion with compression occurs along north-east trending faults in the Arabian plate. The African plate, to the west of the rift, is slower moving than the Arabian plate. Left-lateral motion with tension therefore occurs along north-west trending branch faults (including the Gulf of Suez and its extension).

In the past, horizontal motions with large offsets have taken place along the Dead Sea transform fault. The effect of these is most apparent at the entrance to the Gulf of Aqaba, where the Arabian coastline has been displaced relative to Sinai (see Figure 4.2). On the basis of stratigraphic and structural evidence, Quennel (1958) and Freund (1965) have suggested that the same shift can be found further north along the rift. They have shown that Pre-Cambrian to Upper Cretaceous rock units on either side of the fault are displaced by the same amount. This indicates that shear movement along the rift is entirely post-Cretaceous in age (i.e. younger than 63 million years). Freund et al. (1970) demonstrated that all dissimilarities across the rift disappear simultaneously with a 105km southerly shift of the east side of the fault relative to the west. Hence, 105km of left-hand shear has occurred along the Dead Sea transform fault in post-Cretaceous times. This gives an average rate of movement along the fault of 0.4 to 0.6cm/yr.

Whereas plate motion along the Dead Sea transform is fairly well understood, the role of the Sinai peninsula in regional tectonics is still unclear. The peninsula is believed to be a small sub-plate lying between the African and Arabian plates. A complex junction probably occurs where the three plates meet at the entrance to the Gulf of Suez.

Nur and Ben-Avraham (1978) suggest that a major fault-line extends in a north-westerly direction from the top of the Gulf of Suez, passing beneath the Nile delta. The fault marks the junction between the Sinai plate to the north-east and African plate to the south-west. They further suggest that motion along this fault-line is predominantly left lateral strike-slip, combined with a component of extensional spreading in the Gulf of Suez.

There have been numerous detailed studies of the 20th century seismicity of the Dead Sea rift (e.g. Ben-Menahem and Aboodi, 1981). These indicate that the activity is predominantly of shallow focal depth (<70km). Figure 4.1 shows that a number of relatively large earthquakes have occurred along the central and southern sections of the rift this century. Those of 1927 (Jordan/Israel) and 1956 (Lebanon) were particularly destructive (see Table 3.6). In contrast, the northern part of the rift (in Syria) has experienced no significant seismic activity this century.

The seismicity of Sinai is poorly recorded, but Figure 4.1 shows that there have been no major earthquakes in the peninsula since 1900.

4.4.3 The Zagros and Taurus fold mountain belts

The calculated rate of motion of the Arabian plate with respect to Eurasia is approximately 4.8cm/year (Le Pichon, 1968; McKenzie et al., 1970). According to Nowroozi (1971) this is more than sufficient to produce the compressional features that characterise the Zagros and Taurus mountain ranges.

Continental collision has undoubtedly been responsible for the formation of the Zagros fold mountains, which lie along the eastern and north-eastern margins of the Arabian plate, and the Taurus mountains situated along its north-western margin. Together, these mountain chains form part of the trans-Asiatic seismic belt. As mentioned in Section 4.2, this is one of the largest and most active orogenic belts on Earth.

The Zagros fold mountains extend for a distance of approximately 1,500km in a NW-SE direction, and lie along the Iraq/Iran border. Major deformation in the Zagros commenced during the Upper Miocene to Lower Pliocene, probably in response to the separation of Arabia from Africa along the Red Sea rift (Adams and Barazangi, 1984).

The main Zagros thrust fault parallels the Red Sea, and seems to represent the suture zone between the colliding plates of Arabia and Eurasia. According to Ghalib and Alsinawi (1974), there is a small component of right lateral motion along the main thrust. The thrust fault bends towards the west in northern Iraq and continues into Turkey. There is uncertainty as to whether it then joins the Taurus mountain range, or the Anatolian fault systems. In Iraq, folded foothills and the Mesopotamian foreland lie to the south-west of the main Zagros thrust.

The folding and faulting that has taken place in the Zagros mountains has been relatively uncomplicated. Adams and Barazangi (1984) suggest that this is due to the presence of a plastic layer of thick evaporites and salt deposits, which lies between the deformed sedimentary rocks of the Zagros and the pre-Cambrian basement of the Arabian plate. The salt beds have served to decouple the basement from the sedimentary sequences, thereby reducing deformation.

Nowroozi (1972) has suggested that the Zagros are the consequence of subduction of a crustal slab, dipping north or north-east under central Iran. Various other subduction models have been proposed for the Zagros, which vary principally in the number and location of subduction zones they attribute to the collision zone (e.g. Adams and Barazangi, 1984). Ambraseys (1978) has disputed that subduction is taking place along the collision zone. He suggests that the deformation in the Zagros involves "non-rigid" plates capable of undergoing large internal deformations.

Figure 4.1 shows that the seismicity of the Zagros is relatively high. The majority of earthquakes recorded in the region are restricted to a zone approximately 200km wide. Most are shallow events, though intermediate-depth earthquakes do occur. Nowroozi (1971) first commented that the seismicity is greatest in the folded belt and foothills to the south-west of the main Zagros thrust. The seismicity of this zone gradually decreases towards the Mesopotamian foreland (see Figure 4.1). The main Zagros thrust itself seems to be largely aseismic.

The Taurus fold mountains are similar to those of the Zagros, and mark the northern boundary of the Arabian plate. They probably link the Levant fracture zone in the west with the Zagros mountains in the east. Figure 4.1 shows that moderate seismic activity has been experienced in the Taurus region this century. According to Nowroozi (1971), most of the activity is of shallow focal depth (<70km) and is associated with the main Taurus suture. The foreland and foothills of the mountains seldom experience earthquakes.

4.4.4 The North and East Anatolian transform faults

Both these fault systems are situated in Turkey, and therefore lie outside the Middle Eastern region proper (as defined in Section 3.2). Despite this, a discussion of the faults is necessary because of their close relationship to (and interaction with) the major tectonic zones of the Middle East. In addition, seismic activity along the Anatolian faults occasionally affects parts of northern Syria and Iraq.

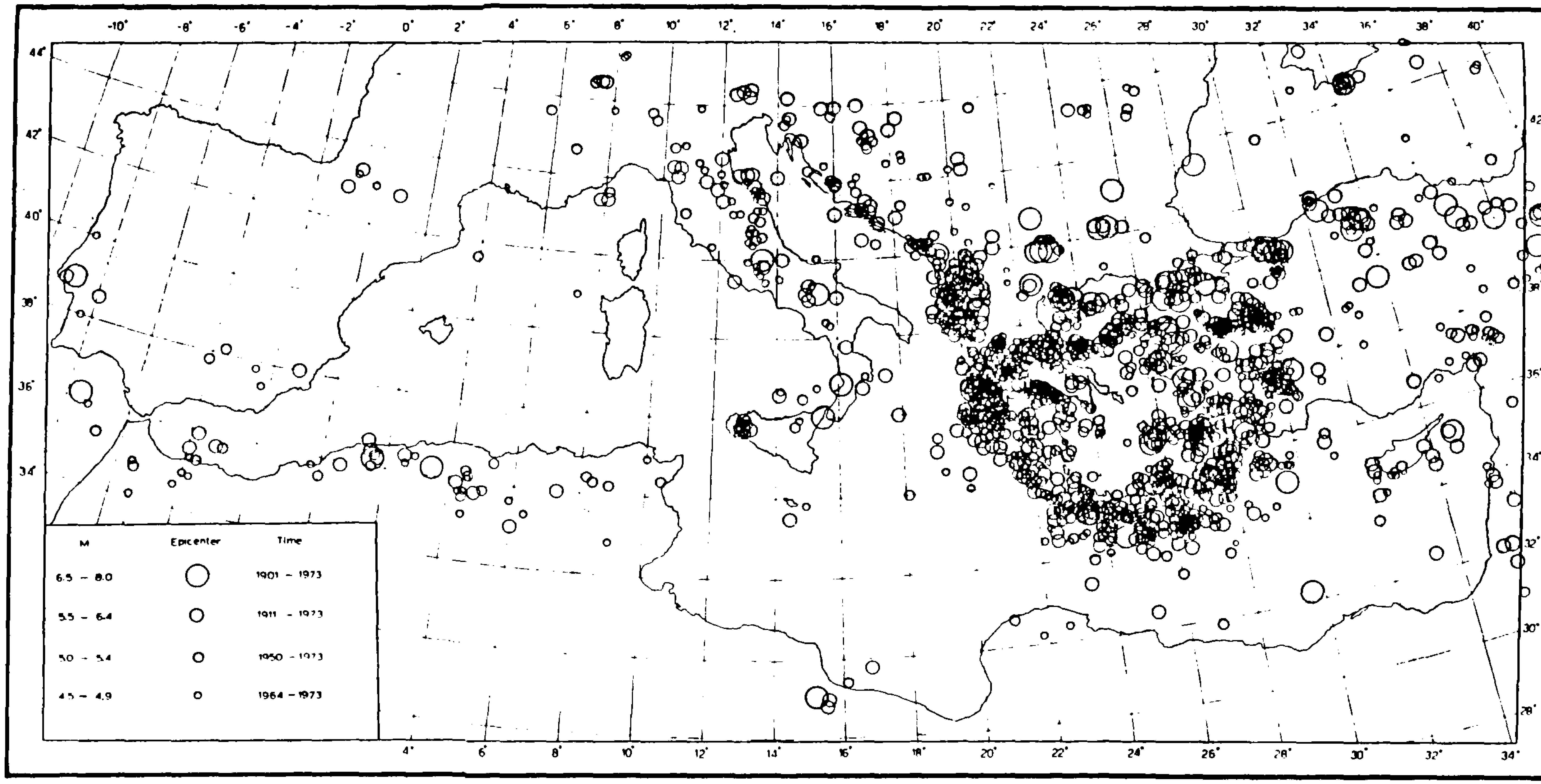
The Anatolian fault systems have been produced as a direct consequence of the collision between Arabia and Eurasia during the Mid- to Upper-Miocene. A small sub-plate, the Turkish or Anatolian plate, was formed in response to this collision (see Figure 4.2). This plate is bounded on its northern side by the North Anatolian transform fault, and on its southern side by the East Anatolian transform fault.

The Turkish plate is moving west with respect to both Eurasia and Africa, due to the wedging-out effect produced by the convergence of the two major plates. McKenzie (1970), Sengor (1979) and Harsch and Kuepfer (1980), suggest that this wedging process allows convergence to take place without the need for excessive crustal thickening along the collision front in Anatolia. Instead, the shortening is accomodated by subduction of oceanic plate along the southern margin of the Turkish plate. North (1974) and Harsch and Kuepfer (1980), have further suggested that much of the deformation in the Turkish plate, is taken up by non-elastic creep within the Anatolian fault zones.

The North Anatolian transform is a right-lateral shear fault. It extends for a distance of over 1,200km, from the Gulf of Saros in the west to just south of Erzurum in the east. Sengor (1979) has calculated that the total offset along the fault is approximately 85km. Arpat and Saroglu (1972) have estimated that the average rate of motion along the fault is about 1-2cm per year, whereas McKenzie (1970) cites a slip rate of 11cm per year. East of Erzincan, the type of motion along the fault switches from strike-slip to thrusting, with the European plate over-riding the Turkish plate (McKenzie, 1970). In the west, the North Anatolian fault is supposedly continuous with the northern boundary of the Aegean plate.

The East Anatolian transform is a left-lateral shear fault. It extends from the Gulf of Iskenderun in the west, to a possible junction with the North Anatolian fault east of Erzincan. The fault forms part of the southern boundary of the Turkish plate. It

Figure 4.3



Distribution of the epicenters of the shallow ($h < 60$ km) earthquakes in the Mediterranean and surrounding area.

After Papazachos and Comninakis (1978, p.289) probably continues offshore as a tectonic arc that runs south of Cyprus, before joining the southern boundary of the Aegean plate to the south-west of the Turkish mainland (McKenzie, 1970).

One of the better known aspects of the Anatolian fault zones is their seismicity. Figure 4.3 shows that a number of large earthquakes have occurred along the faults during the 20th century. Ambraseys (1978) has been able to demonstrate that the North Anatolian fault is characterised by periods or "bursts" of seismic activity separated by quiet phases of about 150 years duration. The present cycle of activity along the fault began with a large earthquake in December 1939 (Gutenberg and Richter, 1965), after which activity gradually progressed in a westerly direction (Ketin, 1948).

Figure 4.3 shows that the active zone surrounding the Anatolian faults ends abruptly at a longitude of approximately 20E. Similarly, there is a fairly definite northern boundary to the activity at latitude 41N. Ambraseys (1970) has shown that in the middle portions of the North Anatolian fault, earthquakes are infrequent and aseismic slip may be important.

The majority of earthquakes that occur along the North and East Anatolian faults are of shallow focal depth. Some earthquakes of intermediate depth have been recorded around the Gulf of Iskenderun.

4.4.5 The eastern Mediterranean basin

Due to the complexity of the tectonics and deep structure of the eastern Mediterranean basin, knowledge regarding its tectonic history is limited. McKenzie (1970) and Comninakis and Papazachos (1972), consider the development of the Mediterranean basin to be the result of crustal shortening, due to the northerly movement of the African plate relative to Eurasia. A large ocean (Tethys) existed between Eurasia and Africa during the Cretaceous and early Tertiary periods. The present Mediterranean is believed to be a remnant of this ocean.

Tectonically, the Mediterranean Sea is divided into western and eastern basins by the Calabrian arc. This arc comprises Calabria, Sicily and the Straits of Sicily. A subduction zone is believed to dip beneath it towards the north-west (Papazachos, 1973). The Calabrian arc is discussed in greater detail in Section 4.5.4.

Important differences exist between the eastern and western Mediterranean in respect of almost all geophysical properties (Papazachos and Comninakis, 1978). Figure 4.3 shows that seismic activity is considerably greater in the eastern Mediterranean, and that large earthquakes of magnitudes greater than 7.0 are of much more common occurrence than in the west. Some of the intermediate-depth earthquakes of the eastern Mediterranean basin are, in fact, the largest in Europe. Sieberg's (1932) isoseismal maps show the enormous areas shaken by some of these shocks; it is not uncommon for them to be felt in Egypt, Libya, the Levant, Turkey, Greece and in countries bordering the Adriatic.

The reason for the greater seismic activity of the eastern Mediterranean basin, is the complicated interaction between oceanic and continental crust that is taking place within it. Of particular importance is the presence of two small, rapidly moving, sub-plates (the Aegean and Turkish plates) in the eastern Mediterranean. The Turkish plate was discussed in Section 4.4.4.

Most seismic activity in the eastern Mediterranean is located along the boundaries of the Aegean plate. The Aegean plate is moving south-west relative to the Eurasian plate, producing extension and strike-slip along the boundary between them. The southern boundary of the Aegean plate is underthrust by the African plate along a tectonic trench termed the Cretan arc (also referred to as the Hellenic or Aegean arc). The direction of the underthrusting is south-north (see Figure 4.2). Proof of subduction along the Cretan arc has been provided by McKenzie (1970) and Papazachos and Comninakis (1978). They have shown that north of the Cretan arc the focal depth of earthquakes increases from south to north, and that intermediate-depth earthquakes are common beneath Greece and the southern part of the Aegean (maximum depth of approximately 200km). In addition, active and dormant andesitic volcanoes occur in Greece and some of the Aegean islands. For example, Thera (Santorini). Volcanoes of this type are frequently associated with subduction zones.

Papazachos (1973) has suggested that the mean dip of the African plate beneath the Cretan arc is 35 degrees, whereas Maamoun and Allam (1981) calculate a dip of less than 50 degrees. The mean rate of subduction along the arc is approximately 2.8cm/year (Papazachos, 1973).

Figure 4.2 shows that to the east of the Cretan arc lies the Cyprian arc. This has resulted from the underthrusting of the Turkish plate by the African plate. The angle of subduction along the Cyprian arc is less than 20 degrees (Maamoun and Allam, 1981). As a consequence of this shallow dip, the maximum focal depth of earthquakes in this part of the Mediterranean (approximately 140km) is less than that associated with the Cretan arc. Figure 4.3 shows that the Cyprian arc is considerably less seismically active than the Cretan arc.

Nur and Ben Avraham (1978) suggest that as well as underthrusting, some of the deformation along the Cyprian arc consists of strike-slip faulting. This type of faulting becomes increasingly important to the east of Cyprus, where active subduction beneath the southern boundary of the Turkish plate gradually ceases to take place. In the extreme north-eastern corner of the Mediterranean basin, focal mechanisms of shallow earthquakes in the Gulf of Iskenderun reveal left-lateral strike-slip motion along a fault orientated NE-SW (Maamoun and Allam, 1981). This is probably continuous with the East Anatolian transform fault.

Along the continental margin of the Levant, seismic activity is entirely of shallow focal depth. It is centred along offshore faults which are downthrown on the seaward side. According to Nur and Ben-Avraham (1978) these have resulted from downfaulting of oceanic crust relative to continental crust, as the former approaches the Cyprian arc. They suggest that large earthquakes along the faults (of magnitudes greater than 6.0) are highly likely to generate tsunamis.

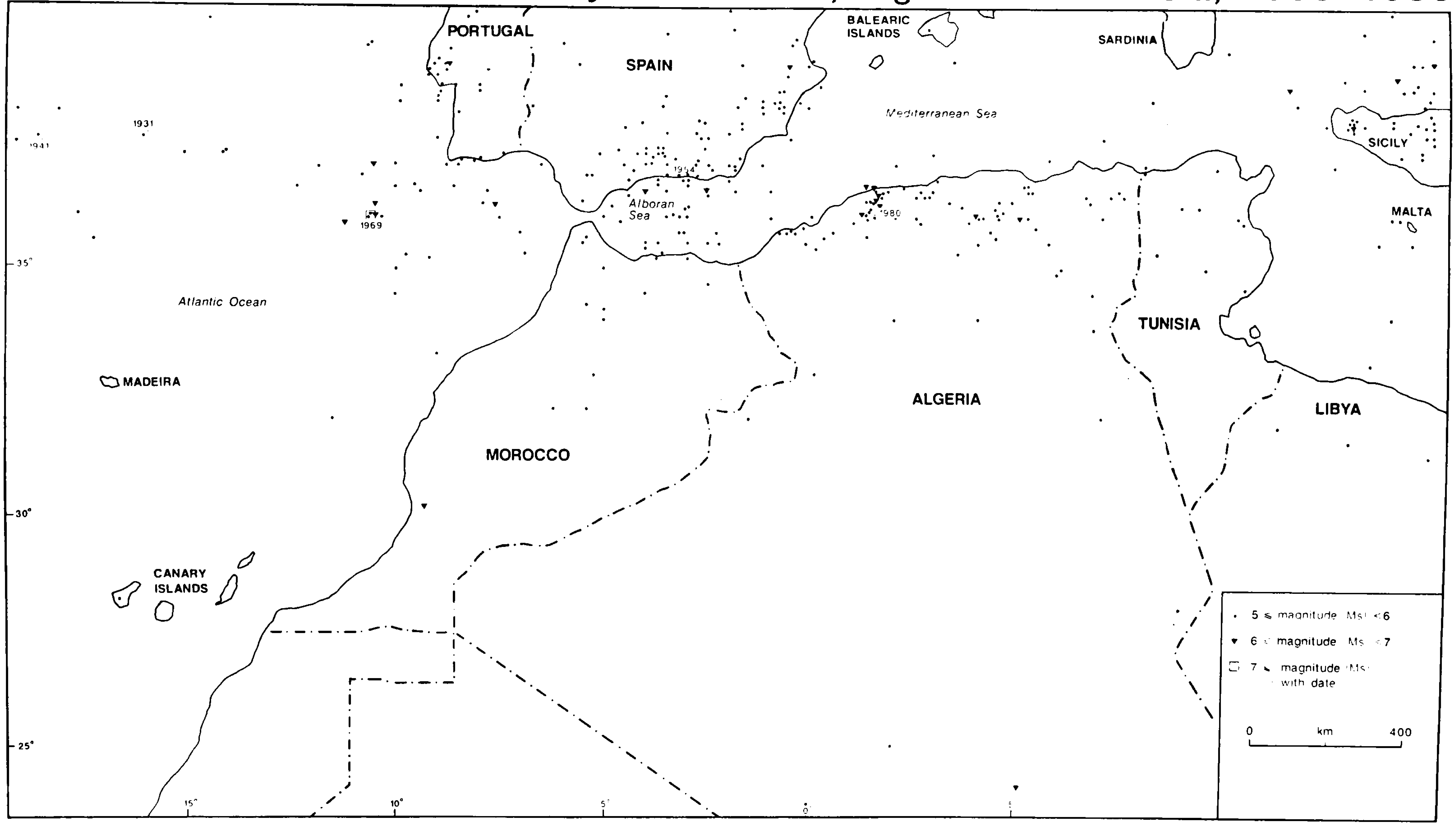
Neev et al. (1973) claim to have identified a major tectonic element (the "Pelusium line") in the south-eastern corner of the Mediterranean basin, 60km off the coast of Israel (see Figure 4.2). It trends parallel to the Levantine coast, and probably represents the western limit of the Sinai plate. Neev (1975) suggests that the Pelusium line extends in a south-westerly direction under the Nile delta and into the central Sahara. Indeed, a major fault-line following this trend is marked on the International Tectonic Map of Africa (Choubert and Faure Muret, 1968), and on the Seismotectonic Map of Egypt (Maamoun et al., 1980). However, studies of the seismicity of the Levantine coast carried out by Ben-Menahem and Aboodi (1981) found no evidence of the Pelusium line off Israel. Confirmation of the existence of this major tectonic unit awaits further investigation.

Faulting within and offshore of the Nile delta is indicated by the presence of localised earthquakes. Maamoun and Allam (1981) suggest that the seismic activity of the Nile cone may be related to local isostacy. This is because the entire delta region is characterised by thinner crust and sedimentary deposits than the rest of the eastern Mediterranean basin.

4.5 SEISMOTECTONIC ANALYSIS OF THE MIDDLE EAST (Western part)

Table 3.6 shows that some of the most destructive earthquakes to have affected the Middle East during the present century have occurred in the western part of the region (North Africa). For example, the Agadir (Morocco) earthquake of February 29, 1960 killed over 12,000 people and caused economic damage estimated at US$ 120

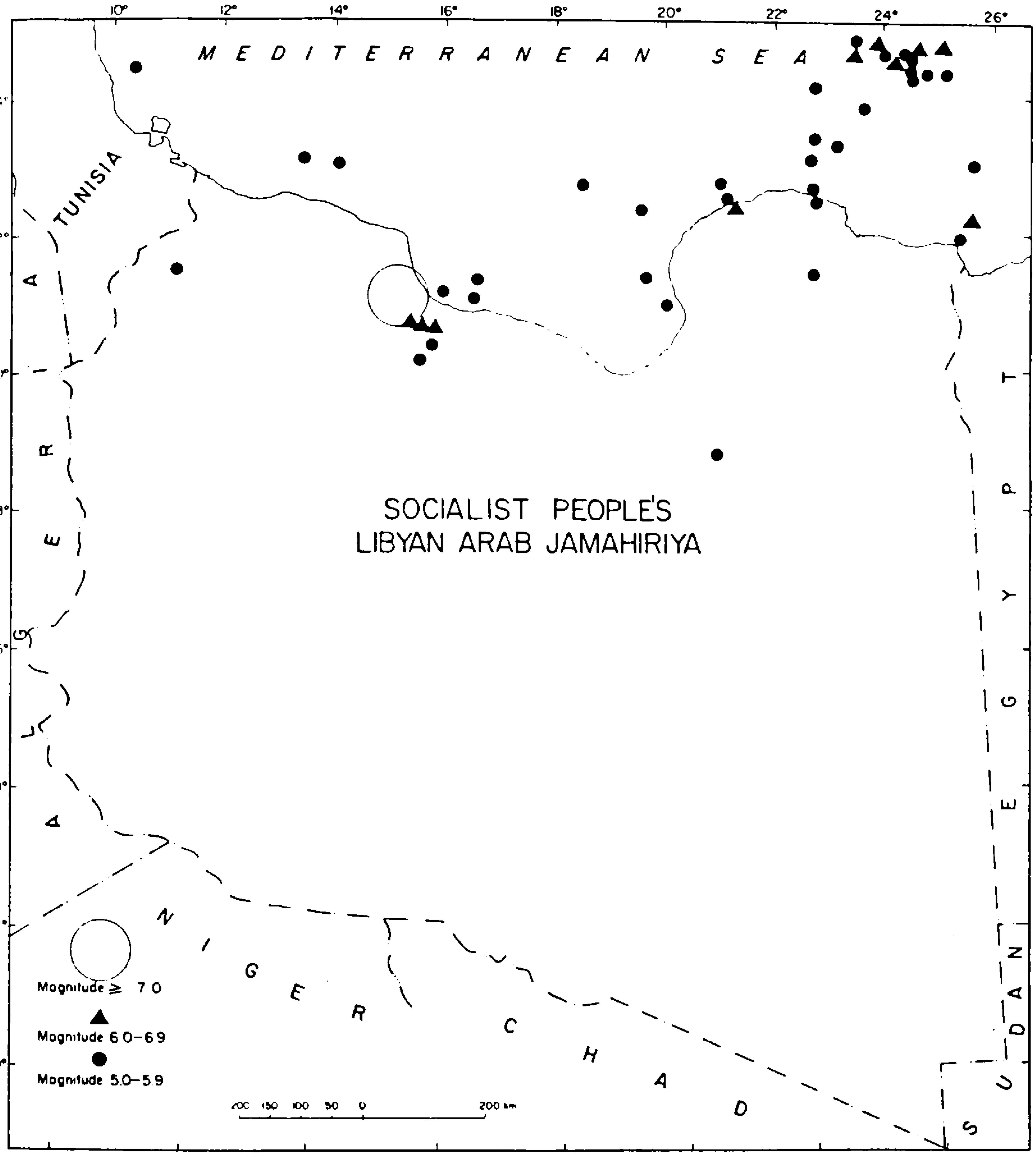
Figure 4.4 Earthquake activity in Morocco, Algeria and Tunisia, 1900–1983



Based upon data provided by the British Geological Survey, Edinburgh

Figure 4.5

Earthquake activity in Libya, 1900-1977



Modified from Kebeasy (1981, p.31)

million. More recently, the El Asnam (Algeria) earthquake of October 10, 1980 killed 2,590 people and cost the country an estimated US$ 2,200 million.

The spatial distribution of 20th century earthquakes in North Africa is shown in Figure 4.4 (Morocco, Algeria & Tunisia) and Figure 4.5 (Libya). Once again, only earthquakes of magnitudes greater than 5.0 are marked upon the maps for reasons outlined in Section 4.4.

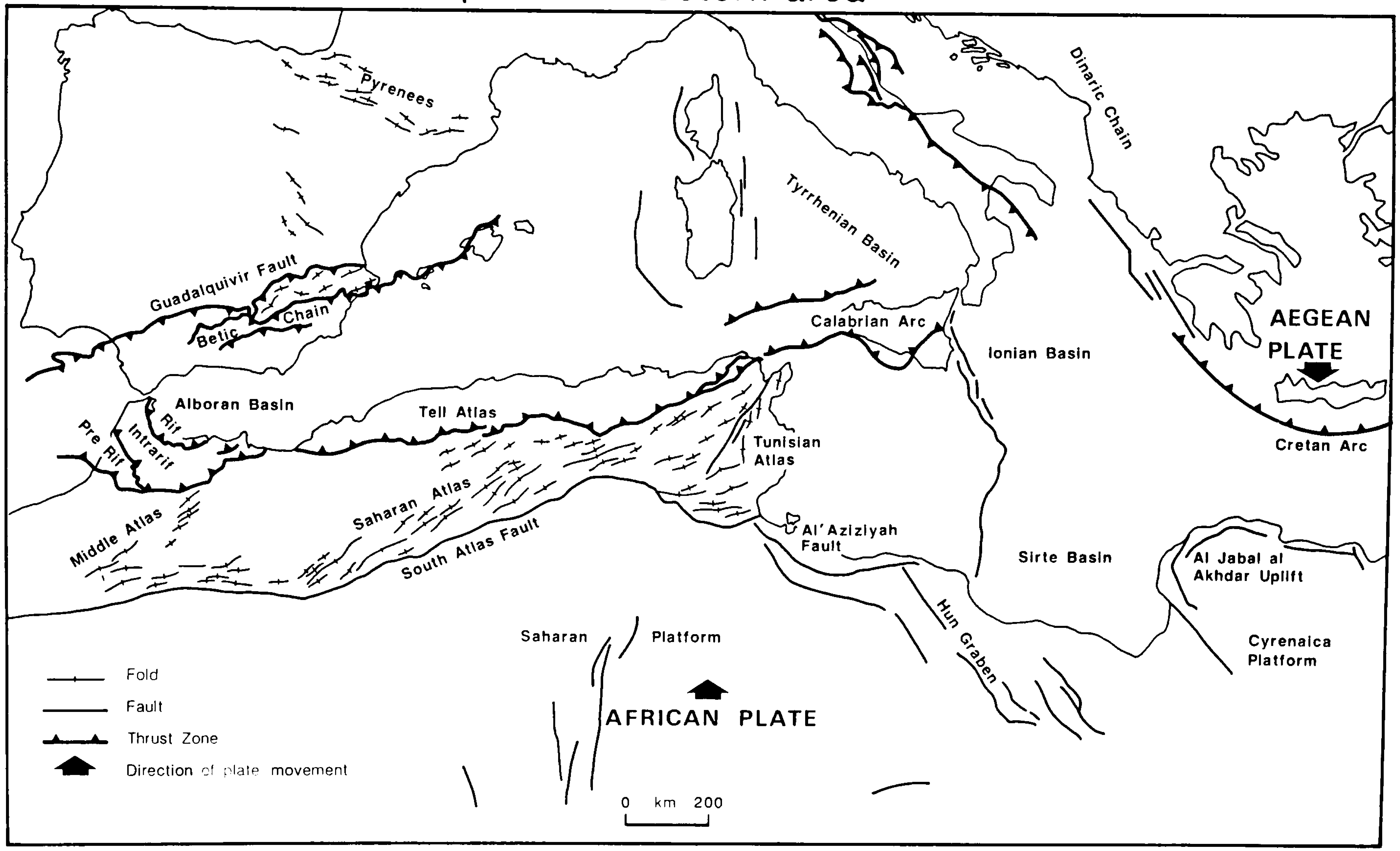
The earthquake epicentres shown in Figures 4.4 and 4.5 define the boundaries of the major tectonic units in this part of the Middle East. These units are illustrated in Figure 4.6, and fall into two main groups:

a) Onshore tectonic zones - including the Rif and Atlas mountain belts of Morocco, Algeria and Tunisia, and the less pronounced onshore tectonic zones of Libya (Hun graben and Al Jabal Al Akhdar uplift);

b) Offshore tectonic zones - including the Azores-Gibraltar ridge, the Calabrian arc, and other zones of more minor offshore faulting.

These tectonic zones are related to compressional and tensional stress regimes, that have resulted both from the spreading processes of the eastern North Atlantic basin (in a west-east direction), and the northerly displacement of the African continent relative to Europe. As mentioned in Section 4.4.5, during the Cretaceous and early Tertiary period a large ocean (Tethys) existed between Eurasia and Africa. The northerly drift of the African plate has gradually

Figure 4.6 Tectonic map of the western area



Based upon maps by Boccaletti et al. (1985) and Choubert and Faure Muret (1968) closed this ocean, to leave the present Mediterranean as a remnant of Tethys. The Alpine fold belt has formed in response to the crustal shortening associated with the collision between Africa and Eurasia.

4.5.1 The Azores-Gibraltar ridge

This marks the boundary between the Eurasian and African plates in the Atlantic Ocean. A seismic belt running between Gibraltar and the Azores clearly defines the position of the ridge (see Figure 4.4). At the Azores, the ridge forms a triple junction with the mid-Atlantic ridge (Udias et al., 1976), and is associated with some active volcanism.

The Azores-Gibraltar ridge has generated some large magnitude earthquakes this century. For example, those of 1941 and 1969 (both of magnitude 8.0 or greater). These earthquakes serve to demonstrate that accumulated strain on the fracture is released periodically by large magnitude events. The earthquakes typically have an average focal depth of around 20km, and show almost pure strike-slip motion (Udias et al., 1976).

The seismicity of the area east of Gibraltar has a different character from that observed to the west. Figure 4.4 shows that the epicentral distribution of earthquakes in the Alboran and Betic regions is much more scattered than that of the Azores-Gibraltar ridge. Udias et al. (1976) suggest that this supports the presence of a sub-plate (Alboran plate) in the region, lying between the Eurasian and African plates. Hatzfeld and Frogneux (1981) prefer to interpret the pattern as reactivation of old tectonic faults, whereas Arana and Vegas (1974) explain the scattered seismicity in terms of a shear zone with microplate individualization. They suggest that this shear zone has been created by splitting of the Azores-Gibraltar ridge into several lineaments, each separated by small blocks with different relative movements.

It is likely that the type of motion taking place between the African and Eurasian plates changes in the Gibraltar region. Mckenzie (1972) suggests that the motion is of a strike-slip nature in the Azores (possibly with a small component of extension), but changes to overthrust south of Spain and across North Africa. Udias et al. (1976) have shown that the strike-slip motion between the Azores and Gibraltar is of a right-lateral type, and have confirmed that this changes to north-south compressive forces and reverse faulting near to the Straits of Gibraltar. A focus of deep seismic activity exists in southern Spain, which Hatzfeld and Frogneux (1981) have suggested could be associated with the subduction of oceanic lithosphere along the boundary between the Eurasian and African plates.

Seismic activity in the Alboran Sea stops at about 1E. This marks the beginning of the western Mediterranean aseismic block. Figure 4.4 shows that the western Mediterranean has not been affected by any marked geodynamic activity during the present century, in contrast to the eastern Mediterranean (see Section 4.4.5 and Figure 4.3).

4.5.2 The Rif and Atlas mountain belts

Complex continental collision exists in north-west Africa, along the Rif and Atlas mountain chains of Morocco, and the Atlas of Algeria and Tunisia. These mountains form part of the Alpine fold belt, and parallel the North African coast. They have formed as a result of the complex convergence and collision that has been taking place between the African and Eurasian plates since the Mesozoic. Recent earthquakes, together with the evidence of widespread Quaternary faulting and folding, indicate that these belts are still tectonically active.

Figure 4.6 shows that the Rif belt curves sharply to the north-west to join the Betic Cordilleras of southern Spain. According to Adams and Barazangi (1984) folding and thrusting have affected the Rif since Eocene times, resulting in an estimated total shortening of more than 100km. They identify 3 main zones within the Rif:

a) Rif;

b) Intra Rif;

c) Pre Rif.

The Intra Rif and Pre Rif have been greatly affected by tectonic thrusting. The final tectonic episode in the evolution of the Rif was uplift (accompanied by volcanic activity) during Neogene and Quaternary times.

The Rif mountain belt of northern Morocco links with the Tell Atlas ranges of Algeria. The Atlas mountain belt is approximately 2,000km long. Its southern margin is marked by the South Atlas fault, which lies 200-400km inland from the Mediterranean coast (see Figure 4.6). During the Cenozoic, folding and thrusting were predominant in the Atlas. The Pliocene and Quaternary were characterised by vertical uplift (Adams and Barazangi, 1984). Major faults occur in all parts of the Atlas.

Recent earthquakes in the Rif and Atlas have been associated with thrust faulting, occasionally with minor components of strike-slip movement (e.g. Yielding et al., 1981). The vast majority of earthquakes in the region are of shallow focal depth, though Hatzfeld and Frogneux (1981) have reported the occurrence of intermediate-depth events beneath the High Atlas of Morocco. Earthquakes as deep as 160km have been located, though the tectonic setting of these events is not fully understood (Hatzfeld and Frogneux, 1981; Adams and Barazangi, 1984).

Figure 4.4 shows that during the 20th century, seismic activity in the central part of the Atlas (Algeria) has been considerably greater than that in Morocco or Tunisia. Within Algeria, the Tell Atlas have experienced a far higher incidence of earthquakes than the Saharan Atlas. From the records of seismic activity, Ambraseys (1981) has estimated that the annual slip rate in the Atlas is only about 0.7mm. This is a small fraction of the amount of movement calculated for the region from plate motions, and implies that much of the deformation takes place aseismically. The implications of this for earthquake hazard assessment in the region will be discussed in Section 4.6.

4.5.3 The Saharan platform

The Saharan platform lies south of the South Atlas fault, and forms part of one of the African cratons. As such, it is mostly covered by thick, undeformed, Palaeozoic strata. Figure 4.4 shows that away from the tectonic zones that fringe it, the platform is largely aseismic.

4.5.4 The western Mediterranean basin and Calabrian arc

As mentioned in Section 4.4.5, striking differences exist between the eastern and western Mediterranean basins as far as geophysical properties are concerned (e.g. Papazachos, 1973). The seismicity of the western Mediterranean is much less than that of the eastern Mediterranean, where large earthquakes of magnitude 7.0 or greater are common (see Figure 4.3). The main reason for this dramatic change would seem to be that the western Mediterranean does not contain the small, rapidly moving, sub-plates that characterise the seismically active areas of its eastern counterpart. Indeed, the whole of the western Mediterranean is thought to form one aseismic block bounded by active tectonic zones (Papazachos, 1973).

The Calabrian arc marks the eastern margin of the western Mediterranean aseismic block. It is formed by Calabria and the Straits of Sicily, and is thought to be continuous with the Atlas mountains of North Africa (Allan and Morelli, 1971). The arc separates the Tyrrhenian basin on its concave side from the Ionian basin on its convex side. Peterschmitt (1956) recognised a Benioff zone along the Calabrian arc, dipping to the north-west beneath the

Calabrian and Tyrrhenian Seas. The main evidence for subduction comes from the presence of intermediate and deep-focus earthquakes (in addition to earthquakes of shallow focal depth). Earthquakes with a maximum focal depth of approximately 500km have been recorded in the region of the arc (Pasquale and Polinari, 1978).

Further evidence that lithospheric subduction is taking place along the Calabrian arc, has come from the interpretation of high gravity and thermal anomalies in the area (Pasquale and Polinari, 1978). In addition, the arc has been associated with considerable historical and recent volcanic activity. There are currently 7 major volcanoes along it, situated in western Italy, the Lipari Islands and Sicily.

Papazachos (1973) has determined an angle of dip of 60 degrees in a west-north-west direction for the Calabrian arc subduction zone. He has calculated that the rate of subduction in this direction is about 6cm per year. All the evidence suggests that the Calabrian arc is an island arc that it is being underthrust by the floor of the eastern Mediterranean basin.

North-east of Sicily, the boundary between the Eurasian and African plates is poorly defined. It has been suggested that the plate boundary either extends across the southern end of the Adriatic to join the Cretan arc, or bends around the Adriatic through Italy and Yugoslavia. The latter case is thought to be the more likely.

4.5.5 The tectonic zones of Libya

Libya is situated on the Mediterranean foreland of the African shield. It is not considered a highly active seismic region (Gutenberg and Richter, 1965), though the northern parts of the country do experience considerable earthquake activity.

Tectonically, the country is more akin to Egypt and north-east Africa than to the countries of north-west Africa. This is because the major fault systems of Libya trend north-west and north-east, and are therefore parallel to the Red Sea and other East African rifts. The major structural features of Libya and environs were first listed by Conant and Goudarzi (1967). Kebeasy (1981) has since identified a number of seismotectonic zones in the country.

An arcuate fault of probable Tertiary age separates the Cyrenaica platform (Al Jabal Al Akhdar uplift) from the depressed Sirte embayment to the west and south-west, and the Mediterranean basin to the north (see Figure 4.6). The uplift is characterised by the frequent occurrence of small to moderate earthquakes, with shallow and intermediate focal depths. It has become very active in recent years. The nature of the seismicity suggests that the platform is continuing to uplift, while the Mediterranean sea-floor is subsiding (Kebeasy, 1981).

The Sirte embayment comprises the Gulf of Sirte and its extension inland. It is characterised by the occurrence of large earthquakes of shallow focal depth (<45km). Figure 4.5 shows that earthquakes tend to occur along the margins of the gulf, and are therefore probably associated with tectonic movements along boundary faults.

The western side of the Sirte embayment is formed by the Hun graben and its offshore extension. The graben is one of the most marked onshore tectonic structures in Libya, and trends parallel to the major rifts of East Africa. It has been relatively active this century, as illustrated by the magnitude 7.1 earthquake that occurred east of the graben in 1935 (Kebeasy, 1981).

Most of the southern part of Libya belongs to the seismically stable Sahara block (Gutenberg and Richter, 1965). Figure 4.5 shows that no significant seismic activity has been recorded in this part of the country during the present century.

4.6 THE VALUE OF TWENTIETH CENTURY SEISMIC DATA FOR EARTHQUAKE HAZARD ASSESSMENT

As mentioned in Section 4.1, 20th century earthquake data have to their advantage the fact that they have been recorded instrumentally. The data therefore contain relatively accurate information concerning the location, depth and size of earthquakes. As a result, they are ideally suited to the type of seismotectonic hazard analysis presented in the present chapter.

However, data of this type can sometimes give a misleading impression of the true distribution of earthquake hazard. Ambraseys (1971) has shown that it is unwise to base long-term hazard evaluations on 20th century data alone. This is because the length of time covered by the data is simply too short, when compared to the geological time-scale on which tectonic processes operate. This is particularly the case in a region like the Middle East, where:

- Instrument networks monitoring local seismic activity are poorly developed;

- Rates of earthquake activity are not particularly high;

- Large amounts of deformation take place aseismically. For example, in the Zagros and Atlas mountain belts (see Sections 4.4.3 and 4.5.2), and in parts of the Anatolian fault zones (Section 4.4.4).

Due to these limitations, tectonic activity in the Middle East is poorly reflected by short-term seismicity. This serves as a serious handicap to earthquake hazard assessment in the region.

The dangers of basing Middle Eastern earthquake hazard assessments on 20th century data alone were highlighted by the 1982 earthquake at Dhamar (Yemen Arab Republic). The earthquake killed or injured almost 15,000 people, and rendered more than 500,000 homeless (Cidlinsky and Rouhban, 1983; p.7). Table 3.6 shows that the economic losses associated with the earthquake totalled US$ 218 million.

The Dhamar disaster was totally unforseen. This was because up until the earthquake, the Arabian peninsula had often appeared completely aseismic on maps of world seismicity. Indeed, Figure 4.1 shows that there has been a general absence of earthquakes in the peninsula during the 20th century. "Surprise" earthquakes such as that at Dhamar will continue to occur in the Middle East, so long as the sole basis for earthquake hazard assessments is the limited amount of instrumental data so far available.

4.6.1 Overcoming the limitations of twentieth century data

One simple way of overcoming the limitations placed on earthquake hazard assessments by 20th century data, is to include analyses of historical earthquake records. The advantages of using historical data are:

- They serve to improve hazard assessments for areas that experience earthquakes infrequently;

- They permit the analysis of rare, large-magnitude earthquake events.

As far as historical earthquake data are concerned, it is fortunate that the Middle East has a long and well-documented history. Indeed, it is one of the few areas of the world where historical records spanning several millenia exist. The written accounts of Biblical scribes, Greek and Roman philosophers, and Muslim chroniclers, all serve to provide a fascinating insight into the types of natural hazard that have affected the region throughout documented human history. Such a wealth of information is obviously invaluable as far as earthquake hazard assessment is concerned.

Unlike the catalogues of 20th century earthquake activity referred to in Section 4.3, no comprehensive catalogue of historical earthquakes exists for the entire Middle Eastern region. A major part of the study has therefore been dedicated to the compilation of such a catalogue. The aim has been to produce a catalogue that can be used as a backward extension of the 20th century seismic data to permit improved assessments of earthquake hazard in the Middle East. The next chapter is devoted to describing the way in which the historical catalogue has been compiled. It also contains a relatively detailed interpretation of the data contained in the catalogue. As such, it takes the analysis of earthquake hazard in the Middle East one stage further from the seismotectonic approach presented in this chapter.

4.7 CONCLUSIONS

In this chapter, 20th century earthquake data have been used to delineate the major tectonic zones of the Middle East. A variety of tectonic environments have been identified, including:

- Zones of plate separation along the Red Sea rift and the Azores-Gibraltar ridge;

- Zones of plate collision along the Zagros, Taurus, and Atlas fold mountains;

- Zones of plate transcursion along the Dead Sea, North Anatolian and East Anatolian transform faults;

- Zones of plate subduction along the Calabrian, Cretan and Cyprian arcs.

20th century seismic data show that the type, frequency and distribution of earthquake activity associated with each of these tectonic environments varies. The identification of the environments and characterisation of their recent earthquake activity, therefore serves to provide an initial impression of the distribution of earthquake hazard in the Middle East. This impression, however, need not be an entirely reliable one. This is because the length of time covered by the instrumental data is simply too short when compared to the geological time-scale on which tectonic processes operate. This is particularly the case in a region like the Middle East where rates of earthquake activity are not particularly high, and where large amounts of deformation take place aseismically.

One way of overcoming this problem is to incorporate historical earthquake data in hazard assessments (i.e. data for earthquakes prior to 1900 AD). The next chapter is devoted to historical aspects of earthquake activity in the Middle East.

CHAPTER 5. HISTORICAL EARTHQUAKE ACTIVITY IN THE MIDDLE EAST

5.1 INTRODUCTION

In Chapter 4, 20th century earthquake activity in the Middle East was summarised. The purpose of this chapter is to examine the historical earthquake activity of the region, in an attempt to gain a more accurate impression of the distribution of earthquake hazard.

The chapter has been divided into two parts. Part One begins by stressing the importance of including historical data in earthquake hazard assessments. Emphasis is placed on the need for a catalogue of historical earthquake activity in the Middle East (comparable to those that are available for 20th century earthquakes). A detailed description is then given of the historical earthquake catalogue that has been compiled for the region during this research programme. The most important sources of historical data are reviewed. Part One concludes with a description of the format of the historical catalogue. The catalogue is listed in Appendices A and B.

Part Two of the chapter is concerned with analysis of the data contained in the catalogue. The distribution of historical earthquake activity is examined, both between and within countries. The chapter concludes with an analysis of other types of natural hazard that have been recorded in association with earthquakes in the Middle East.

PART ONE. THE COMPILATION OF AN HISTORICAL EARTHQUAKE CATALOGUE

5.2 THE NEED FOR A CATALOGUE OF HISTORICAL EARTHQUAKE ACTIVITY IN THE MIDDLE EAST

The previous chapter highlighted the fact that across large parts of the Middle East only moderate levels of seismic activity have been experienced during the 20th century (see Section 4.6). As a result, the amount of instrumental data available is limited, and need not represent a good sample of the long term seismicity of the region. The 20th century data can provide very limited information concerning the frequency of occurrence of large-magnitude earthquakes. Earthquakes of this type are rare, and not easily counted unless the period of observation is long. Hazard evaluations based on instrumental data alone, are therefore likely to lead to underestimations of the true extent and severity of earthquake hazard in the Middle East.

Under such circumstances, careful surveys of historical seismicity (prior to 1900 AD) are absolutely essential, and must be incorporated in assessments of earthquake hazard. Studies of this type serve to extend the sample period over which data are available, and permit more meaningful statistical evaluations to be made. Ambraseys (1971) has demonstrated that historical earthquake data are also valuable, because they help to provide a better understanding of the tectonics of a region. In particular, they serve to highlight any patterns which might exist in the migration of seismic activity between contiguous tectonic units through time. This is of great importance in a region like the Middle East, where complex interaction takes place between a number of continental and oceanic plates (see Chapter 4).

There have been many publications in recent years devoted to aspects of historical seismicity in the Middle East. These have frequently included chronologies of historical earthquakes felt in particular countries or regions. However, to date, no fully comprehensive historical earthquake catalogue has been produced for the entire region. A large part of the research behind the present study has therefore been dedicated to the production of such a catalogue.

There are several advantages to be gained by combining historical earthquake data from a large number of sources to produce a single catalogue that covers an extensive area. These are:

- It enables errors in individual catalogues to be identified and discrepancies corrected;

- It provides a means of introducing homogeneity into the historical data, and emphasises gaps that exist in current knowledge;

- It allows the areal extent of large historical earthquakes to be more accurately ascertained, through detailed analysis of reports from different parts of the region;

- It provides a suitable basis for the study of regional tectonics. It is only by analysing historical earthquake activity over a large area, that the relative interaction of tectonic belts through time can be determined.

5.3 HISTORICAL EARTHQUAKE DATA FOR THE MIDDLE EAST

The Middle East is the only region on Earth where earthquake activity has been documented for over 4,000 years. This documentation is usually in the form of Biblical, ecclesiastical or historical chronicles. The accuracy of these records varies quite considerably through time, as does the comprehensiveness of the coverage that they provide. In early times, the records refer mainly to widespread disasters. For example, the earthquakes recorded in the Bible are probably those of maximal magnitude; references to small disturbances were either not chronicled or were lost. More recently, low-magnitude earthquake events have found a place in history, so that the earthquake records of the last 300 years refer to both large and small events. The earthquakes recorded for recent times are therefore comparatively numerous and very heterogeneous in character, whereas those for early times are few in number, but fairly homogeneous.

In view of this it would obviously be impossible to produce a complete catalogue of historical earthquake activity in the Middle East. The poor preservation of the early historical record prevents this. Nevertheless, sufficient data do exist to permit the compilation of an almost complete listing of the most destructive earthquakes that have affected the region throughout written history. Earthquakes of this type, that had a profound effect upon human populations and the landscape, were documented in a variety of ways. Through careful analysis of the records concerning these events, it should be possible to learn a great deal about this type of earthquake in the Middle East.

5.3.1 Sources of data concerning historical Middle Eastern earthquakes

One problem that is frequently encountered in the collection and analysis of non-instrumental earthquake data, is the tendency for such data to be strongly influenced by the distribution of human populations. This has often served to discourage seismologists from incorporating historical earthquake data in their studies. Amiran (1952) argues that the number of historical earthquakes reported from any one place often bears no relation to the seismicity of the area, but is a reflection of its historical and geographic importance. However, Ambraseys (1975) has been able to show that contrary to popular belief, the documentation of historical Middle Eastern earthquakes is not limited to the most populous sedentary centres. Many desert areas of the region have some recorded history, often in the form of chronicles written in isolated monasteries. Chronicles of this type provide detailed information concerning localised earthquake events in the region.

The oldest records of earthquake activity in the Middle East, are derived from some of the spectacular descriptions that appear in the scriptures of the Old Testament. Archaeological studies of the buried ruins of ancient cities have served to provide some additional evidence concerning these early events (e.g. Karcz *et al.*, 1977), as have geological studies. Ben-Menahem (1976) has suggested a possible correlation between large earthquakes on the Dead Sea fault, and the occurrence of white sedimentary layers in mud profiles taken from the floor of the sea. He has obtained a core of mud which logs earthquake activity along the fault over a period of 2000 years.

Additional historical information has been obtained from the chronicles of Greek and Roman historians. The earliest Greek history was written in ca. 430 BC. Roman records for the period before the sacking of Rome in ca. 390 BC have unfortunately been lost, so that records by Roman historians do not appear before ca. 200 BC. Prior to these dates, Greek and Roman history must be regarded as largely legendary. Roman and Greek scholars continued to chronicle events in the Middle East until 500-600 AD.

The year 630 AD marks the approximate beginning of the Arabic era. Ambraseys (1971) has estimated that in the Middle East, 22% of the most reliable documented historical earthquake events are drawn from Arabic sources. Arabic texts provide most of the historical earthquake data for the region from the time of the initial Moslem conquests in the 7th century, until the 18th century. Records are particularly good for the period between the 9th and 17th centuries.

Poirier and Taher (1980) have listed the following as the most important Arabic chroniclers and historians:

at Tabari, Baghdad (839-922)
Ibn al Qalanisi, Damascus (1073-1160)
Ibn al Djawzi, Baghdad (1116-1201)
Sibt Ibn al Djawzi, Baghdad (1186-1257)
Ibn al Athir, Mosul (1160-1233)
al Maqrizi, Cairo (1360-1442)
As Soyuti, Cairo (1455-1505)

Of these, probably the single most important source is As Soyuti. Ambraseys (1961) describes him as perhaps the most prolific writer in Arabic literature. As Soyuti was an Egyptian polygrapher who produced a catalogue of earthquakes entitled "Describing earthquakes without their din". The catalogue was probably completed between 1499-1505 AD, and lists earthquakes that occurred in Asia and Africa between 712 AD and 1499 AD (Ambraseys, 1961).

19th century earthquake data for the Middle East are derived from a wide range of source materials, including reports in western newspapers and scientific journals. Karnik (1969, 1971) has incorporated both 19th and 20th century data for the region in a comprehensive European catalogue.

5.3.2 Published earthquake catalogues for the Middle Eastern region

As mentioned in Section 5.2, the historical catalogue presented in this study has been compiled using data from a wide range of sources. These sources include a large number of catalogues produced by other workers (usually devoted to particular countries/regions), and information derived from archaeological and geological studies. The catalogue attempts to bring together and unravel the complexity of data that already exist in one form or another. It is to be hoped that it will serve to clarify the historical data, and present them in a format which enables them to be easily used.

Milne (1911) produced the earliest comprehensive account of historical global seismicity. His catalogue lists a number of Middle Eastern earthquakes. More recently, Ganse and Nelson (1981) have produced a catalogue of significant global earthquakes that occurred between 2000 BC and 1979 AD. This also contains a considerable number of references to the Middle East.

Catalogues that are more specific to the Middle Eastern region include that of Ambraseys (1961). This lists historical earthquakes of South-West Asia from 628 AD to 1500 AD. Ben-Menahem (1979) has listed 282 seismic events that occurred within 1600km of Jerusalem from 92 BC onwards. Poirier and Taher (1980) have produced a catalogue of earthquake activity recorded in the Middle East between the 7th and 18th centuries AD. This has been compiled exclusively from Arabic documents. 170 ancient texts were used, drawn from libraries in Cairo, Damascus, Istanbul, Madrid, London and Paris.

A number of earthquake catalogues have been produced for specific countries in the Middle East. The comprehensiveness of these varies quite considerably, as does the period of time that they cover. For example:

- Willis (1928, 1933) has produced a catalogue of earthquakes in the "Holyland". It covers the period 1606 BC to 1928 AD;

- Amiran (1951) has catalogued the historical seismicity of Israel. His list, however, does not include earthquakes prior to 100 BC, "their dates and particulars being too uncertain" (p.223);

- Alsinawi and Ghalib (1975) have produced a very useful summary of historical earthquake activity in Iraq. Their catalogue lists 79 major and minor events that occurred in the country between 1260 BC and 1900 AD;

- Poirier et al. (1980) have listed large historical earthquakes of north-west Syria (52 AD to 1971 AD);

- Ambraseys and Melville (1983) have catalogued the historical seismicity of Yemen for the period 742 AD to 1982 AD;

- Rothe (1950) and Roussel (1973) have produced comprehensive catalogues of historical earthquake activity in Algeria;

- Kebeasy (1981) has listed the data available concerning historical earthquakes in Libya (262 AD to 1977 AD);

- Lions (1907) and Maamoun (1979) have listed the records of large historical earthquakes in Egypt. The earliest event listed by Maamoun dates from 2200 BC.

In addition to country-specific reports, a number of catalogues summarise the records of earthquakes that affected particular Middle Eastern cities. For example, Ambraseys (1962b) has summarised the historical earthquakes of Tunis and its region, whilst Stahl (1971) has conducted a similar survey of Tanger and its region. Kebeasy et al. (1981) have catalogued historical earthquakes that affected Alexandria, Egypt.

Finally, Heck (1947) and Ambraseys (1962) have listed some of the historical tsunamis (seismic sea waves) that have affected the Middle Eastern region. Neumann van Padang (1963), Simkin et al.

(1981) and Stothers and Rampino (1983), have catalogued the historical volcanic activity of the region. The occurrence of phenomena of this type is intimately related to earthquake activity. They have therefore been included in the historical analysis.

Data from all these modern sources, plus that from a wide variety of other less comprehensive works, have been incorporated in the catalogue presented in this study.

5.4 FORMAT OF THE CATALOGUE

The historical catalogue has been compiled with the aid of a computer database system. The advantage of using a system of this type, is that it enables data to be standardised. Each earthquake entry in the catalogue follows the same format, with information recorded under the following headings:

- Date
- Epicent(re)
- Fault
- Intens(ity)
- Mag(nitude)
- Felt in
- Details
- Hazards
- Source
- Comment

Due to the fragmentary nature of historical reports, information for each of the above parameters is not available for many earthquakes. Only those parameters for which data are available are listed for each earthquake event. The types of information recorded under each parameter heading are as follows:

DATE The date of occurrence of the earthquake is given as year BC or AD. Following this, the month and date of the event are listed if known, as is the time (usually given as local time). In cases where uncertainty surrounds the exact date of the event the following format is used:

- AD 551 July 9 - Aug 9 (1)
- AD 551 July 9/Aug 9 (2)

In the first example, the two dates are those between which the earthquake occurred. In the second, the earthquake occurred either on July 9 or August 9.

By using a wide range of sources to compile the catalogue, it has been possible to eliminate many of the errors of previous catalogues. One very common error is for earthquakes to be recorded more than once. For this reason, the records of large events reported by different sources to have occurred in the same area but at dates differing by only a few years, have been treated with caution. Similarly when the day of the month of successive large earthquakes is the same, or when the descriptions of the damage caused are very similar, only the date of the earlier account has been retained. In cases of great uncertainty, all the accounts have been retained, but the similarity of successive events is noted.

Ambraseys (1961, 1962) and Poirier and Taher (1980), have shown that a common cause of error in many historical catalogues is the frequent habit of some early chroniclers to report the earthquake activity and damage for a whole year collectively, as though it were the result of a single earthquake. This can lead to an underestimation of the number of earthquakes for a given year, and an overestimation of their range/size. Careful examination of the historical record, however, allows these anomalous "events" to be identified and corrected.

EPICENT. Wherever possible the earthquake epicentre is given. This is usually defined broadly in geographical terms (e.g. 15km N.E. of Alexandria, Egypt), and sometimes more precisely by latitudinal and longitudinal coordinates. Obviously, for earthquakes prior to the 19th century, estimates of epicentral locations are very approximate. Epicentral locations for 19th century earthquakes are more precisely defined, but considerable error is still to be expected.

FAULT The fault along which the earthquake occurred is listed if known (e.g. Arava fault, Israel).

INTENS. Various authors have been able to assign epicentral intensities (Io) to historical earthquakes. They have done this on the basis of descriptions of damage given in historical documents (e.g. Ben-Menahem, 1979).

The epicentral intensities of earthquakes are given in accordance with the 1956 version of the Modified Mercalli scale (see Table

TABLE 5.1

The 1956 Version of the Modified Mercalli (MM) Scale

Number	Descriptive term	Effects	Acceleration cm s^{-2}
I	Imperceptible	Not felt. Registered only by seismographs.	<1
II	Very slight	Felt in upper storeys solely by persons at rest.	1-2
III	Slight	Felt indoors. Vibrations like those caused by light trucks passing by.	2-5
IV	Moderate	Hanging objects swing. Vibrations like those caused by heavy trucks or a jolt such as that occasioned by a heavy object striking the wall. Parked cars are set in seesaw motion. Windows, doors and crockery rattle.	5-10
V	Fairly strong	Felt outdoors. Sleeping persons wakened. Small objects not anchored are displaced or overturned. Doors open and close. Shutters and pictures are set in motion. Pendulum clocks stop and start or change their speed.	10-20
VI	Strong	Walking is made difficult. Windows, crockery and glass break. Knick-knacks, books, etc. fall off shelves; pictures fall from the walls. Furniture moves or is overturned. Cracks in weak plaster and materials of construction type D. Small bells ring (church, school).	20-50
VII	Very strong	Noticed by car drivers and passengers. Furniture breaks. Material of construction type D sustains serious damage. In some cases, cracks in material of construction type C. Weak chimneys break at roof level. Plaster, loose bricks, stones, tiles, shelves collapse. Waves created on ponds.	50-100
VIII	Destructive	Steering of cars made difficult. Very heavy damage to materials of construction type D and some damage to materials of type C. Partial collapse. Some damage to materials of type B. Stucco breaks away. Chimney, monuments towers and raised tanks collapse. Loose panel walls thrown out. Branches torn from trees. Changes in flow or temperature of springs. Changes in water level of wells. Cracks in moist ground and on steep slopes.	100-200
IX	Highly destructive	General panic. Material of construction D completely destroyed. Serious damage to material of type C, and frequent collapse. Serious damage also sustained by material of type B. Frame structures lifted from their foundations, or they collapse. Loadbearing members of reinforced-concrete structures are cracked. Pipes laid below ground burst. Large cracks in the ground. In alluvial areas, water, sand and mud ejected.	200-500
X	Extremely destructive	Most masonry and wooden structures destroyed. Reinforced steel buildings and bridges seriously damaged, some of them destroyed. Severe damage to dams, dikes and weirs. Large landslides. Water hurled onto the banks of canals, rivers and lakes. Rails bent.	500-1000 ($\approx$1g)
XI	Disaster	All structures collapse. Even large, well-constructed bridges are destroyed or severely damaged. Only a few buildings remain standing. Rails greatly bent and thrown out of position. Underground wires and pipes break apart.	1-2g
XII	Major disaster	Large-scale changes in the structure of the ground. Overground and and subterranean streams and rivers changed in many ways. Waterfalls are created, lakes are dammed up or burst their banks. Rivers alter their courses.	>2 g

Construction method A: Good workmanship, mortar and design; reinforced, especially laterally, and bound together using steel, concrete, etc.; designed to resist lateral forces.

Construction method B: Good workmanship and mortar; reinforced but not designed to resist strong lateral forces.

Construction method C: Ordinary workmanship and mortar; no extreme weaknesses such as failing to tie in at corners, but neither reinforced nor designed to resist horizontal forces.

Construction method D: Weak materials such as adobe; poor mortar, low standards of workmanship; horizontally weak.

Source: Munich Re. (1978; p.11)

5.1). Occasionally, intensities are given in terms of the Standard Mercalli scale, and are therefore preceeded by the letters (SM).

MAG. Given sufficient data it is not difficult to assess the relative magnitude of historical earthquakes. For instance, a large magnitude event can always be identified by the size of the area over which it was felt, the duration of its aftershock sequence and the degree of damage it caused. It is often possible to use 20th century seismic data to calibrate historical earthquakes of this type. For any given region, the instrumental magnitudes and isoseismal distributions of major 20th century earthquakes can be used to derive empirical intensity/magnitude relations. These can then be employed to assign magnitudes to similar historical earthquakes of unknown magnitude. The value of this approach has been demonstrated for the Dead Sea fault by Vered and Striem (1977).

Wherever possible the magnitude of the historical earthquake is listed. This is usually given on the local magnitude (ML) scale, unless otherwise stated.

FELT IN All the countries in which the earthquake event was felt are listed. For many historical earthquakes, the distribution of affected countries can often provide an indication of the likely epicentral region of the earthquake. For insurance and reinsurance hazard assessments, knowledge of the particular countries/regions affected by an earthquake event, is often more meaningful than data concerning the epicentral location of that event.

In the catalogue, YEMEN A.R. symbolises the Yemen Arab Republic

(North Yemen) and YEMEN P.D.R. symbolises the Yemen People's Democratic Republic (South Yemen).

NB Many historical earthquake reports refer to damage in Antioch. Although Antioch is now Antakya in the extreme southern part of Turkey, the city was once the capital of Syria. For the sake of convenience, Antioch is therefore treated as a Syrian city in the catalogue.

DETAILS This provides a summary of all the important information concerning the distribution and type of damage caused by the earthquake. Casualty figures are also listed wherever possible. For each event, an attempt has been made to interpret the historical reports and provide a summary of the important facts. For a fuller description of the effects of a particular earthquake, the original source texts from which data have been derived should be consulted (see SOURCE).

When interpreting damage reports of historical earthquakes, it is important to take several factors into consideration:

a) As mentioned in Section 5.3.1, historical damage reports tend to be weighted towards centres of greatest population density. Changes in population density through time have a considerable bearing on the extent of information available for a region, as do changes in cultural awareness (often brought on by political changes);

b) Natural exaggerations inevitably occur in the descriptions of early earthquake events. General information about the number of

TABLE 5.2

Criteria for the Appreciation of Intensity

Criteria	Intensity (MM)
"Slight earthquake"	IV-V
"Earthquake", "shocks"	VI-VII
"Violent", "terrible", earthquake, but no mention of victims or destructions	VII-VIII
Houses destroyed, hundreds of victims or less	VII-VIII
Ramparts destroyed, towers, minarets, lighthouse (Alexandria) fall	VIII
City totally destroyed, inhabitants evacuate the city	IX-X
Hot springs, sand ejected, cracks in ground	IX-X
Rivers, wells overflow; people "swallowed into the earth"; mountains are "cleft" or "fall down"; large landslides; villages engulfed in "black water"	X-XI

Source: Poirier and Taher (1980; p.2198) earthquake victims or the number of houses destroyed, may in some cases be exaggerated. Much can be inferred from the nature of the statements used in the damage descriptions. Phrases such as "the city was entirely destroyed" indicate an earthquake of high intensity. Less precise comments like "terrible quake" or "the worst seen", indicate events of lower intensity. Poirier and Taher (1980) have shown that apocalyptic descriptions of earthquake damage often stem from the use of phrases abstracted from the Bible or Koran, and should not be taken too literarily. For example, there are many descriptions of earthquake events that lasted "40 days and 40 nights".

On the basis of historical damage descriptions, several authors have been able to give rough estimates of the intensity of shaking experienced at particular places during earthquakes. Poirier and Taher (1980) used the criteria listed in Table 5.2 for this purpose. Intensity values of this type are included in the catalogue when available.

A problem encountered in the compilation of the catalogue has been the spelling of place names. This is because the names of many countries, regions and towns have changed through time. In most cases, modern names are used in the catalogue. These are spelt according to the definition provided by the "The Times Atlas of the World", (1980). Occasionally, when an old name is still in common use, the catalogue lists this with the modern name in brackets. For example, Sur (Tyre) and Bone (Annaba).

<u>HAZARDS</u> Some historical earthquakes have occurred in association

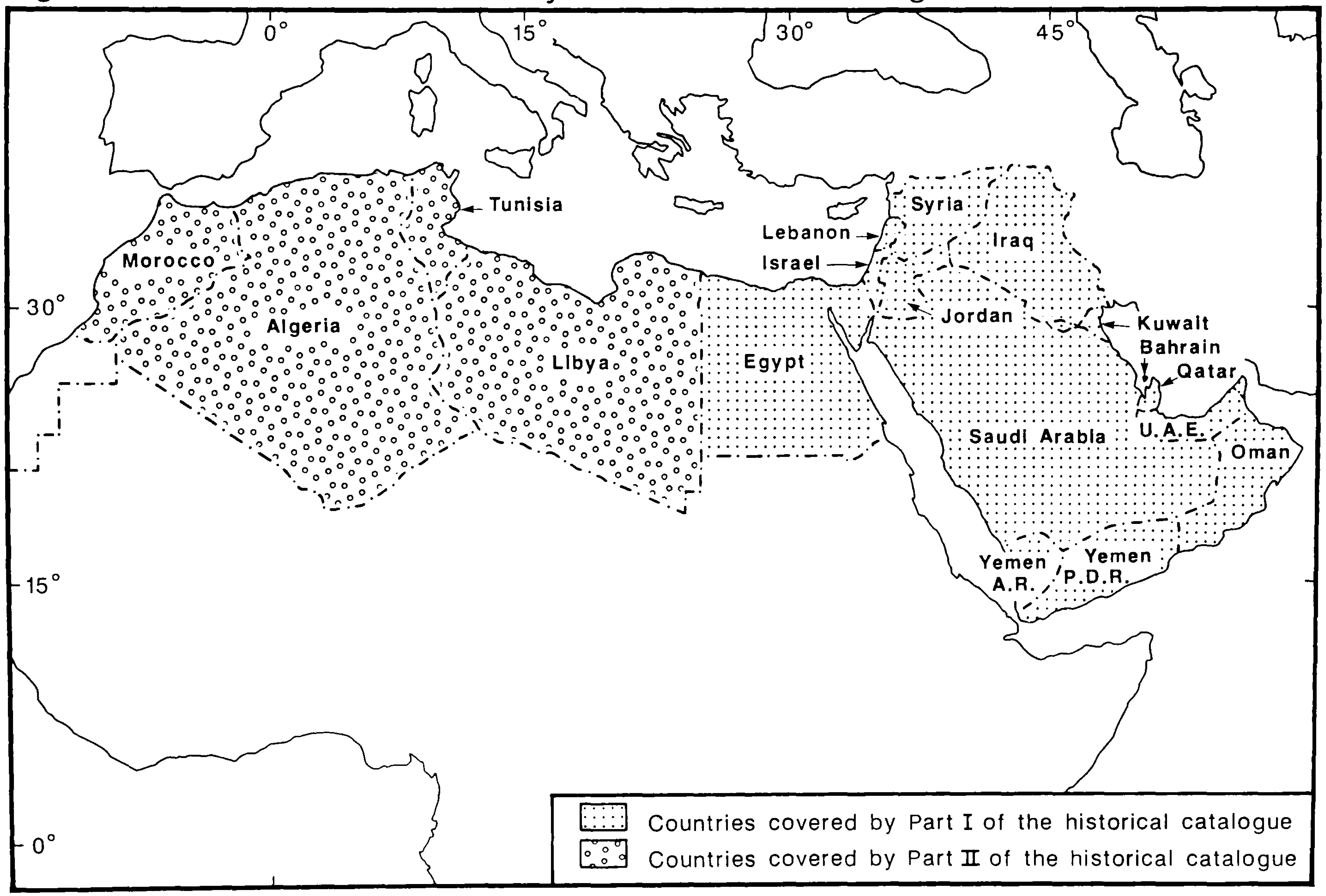
with (or have triggered) other geological hazards. The most important of the associated hazards are tsunamis, seiches, landslides (occasionally abbreviated to "L.slides" in the catalogue), rockfalls, liquefaction, volcanic eruption and faulting. Data concerning these is listed wherever appropriate.

Ambraseys (1978b) has demonstrated that earthquake-induced faulting is quite common in the Middle East. There is considerable evidence to show that both large and small historical earthquakes have been associated with surface faulting. Earthquakes caused by thrust and normal faulting can be distinguished from those caused by strike-slip faulting, because they tend to be associated with a much longer period of damaging aftershocks.

According to Poirier and Taher (1980), cataclysmic descriptions of historical earthquakes are frequently associated with the occurrence of landslides. Mountains are described as having been "cleft", "shattered" or "collided", and people fall into "bottomless fissures". There are vivid accounts of liquefaction in which villages are engulfed by the ground, leaving "still black water" where they once stood. The intensity of shaking associated with ground failures of this type is usually greater than X. Once again, an attempt has been made to interpret these historical statements and to provide a summary of the important facts in the catalogue.

Earthquakes beneath oceans can produce tsunamis (seismic sea waves). These may serve to increase the severity of earthquake impact on low-lying coastal areas. Similarly, an earthquake beneath or close to an enclosed body of water may produce a seiche (an oscillation of

Figure 5.1 Countries covered by the historical catalogue



the entire body of water).

SOURCE Lists the sources from which the historical data have been abstracted. The source items are numbered for ease of reference, and listed at the end of the catalogue. Several of the sources cross-reference, so that the number of different sources cited for a particular event need not reflect the certainty of that event.

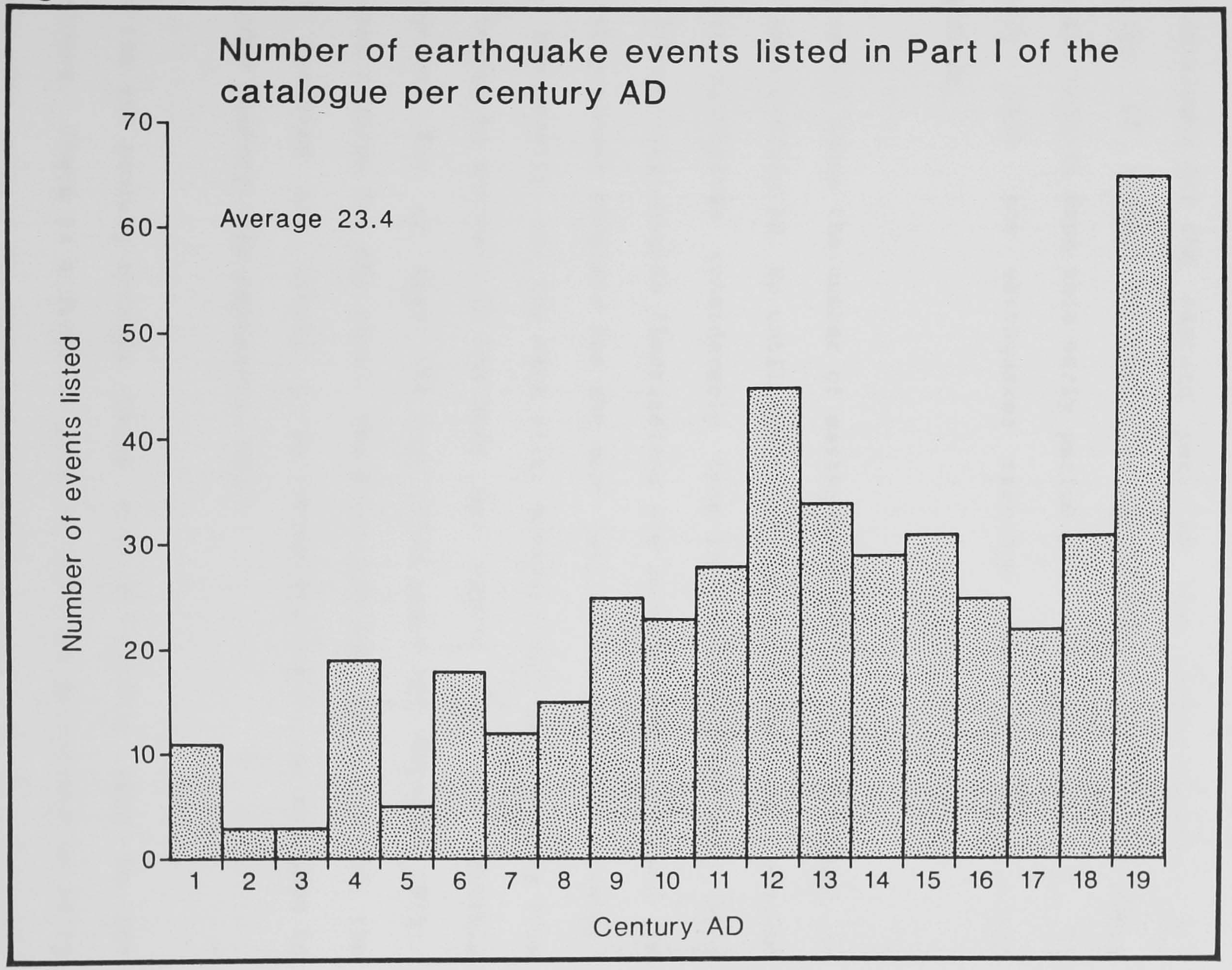
COMMENT Occasionally a comment is added at the end of an earthquake report. This usually refers to some uncertainty concerning the report, or comments upon its similarity to a previous or succeeding earthquake event in the catalogue.

PART TWO. ANALYSIS OF THE HISTORICAL CATALOGUE

In keeping with the format of the two previous chapters, the analysis of historical earthquake activity in the Middle East has been divided into two parts. Two historical catalogues have therefore been produced. Part I (Appendix A) refers to the eastern part of the region, and Part II (Appendix B) to the western part (see Figure 5.1). Each appendix is subdivided into four sections. The first contains the catalogue, the second provides an index of countries (in the catalogue), the third an index of hazards associated with earthquakes and the fourth lists the data sources.

The initial analysis of Part I of the catalogue is presented in Section 5.5, and that of Part II in Section 5.6.

Figure 5.2


Number of earthquake events listed in Part I of the catalogue per century AD
Average 23.4
Number of events listed
0
10
20
30
40
50
60
70
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Century AD

5.5 HISTORICAL SEISMICITY OF THE MIDDLE EAST (Eastern part)

5.5.1 Completeness of the catalogue

The catalogue for the eastern part of the region contains 481 entries. Of these, 36 refer to earthquakes that occurred before Christ. Records from this early period are rather poor, and it is likely that the earthquakes recorded are those of greatest magnitude.

Figure 5.2 shows the number of earthquakes listed in the catalogue for each century AD. Up until the 6th century the number of recorded events fluctuates considerably from one century to the next. From the 6th century onwards fluctuations are reduced, and the record is probably almost complete for the most destructive earthquake events. The homogeneity of the data will, however, vary considerably from one region to another. In the Dead Sea region they are probably homogenous for at least the last 1,500 years (Ben-Menahem, 1979), whereas records for the Sinai, the Negev and the area east of the 40th Meridian are likely to be incomplete due to serious gaps in recorded history (see Ambraseys, 1971).

From the 6th century onwards there are no notable gaps in the catalogue. There is a definite peak in recorded earthquake activity in the 12th century AD. Possible reasons for this will be discussed in Section 6.4. Following the 12th century there is a noticeable drop in the number of earthquakes listed in the catalogue. This is terminated by a rapid rise during the 19th century. This increase is undoubtedly the result of the improved means of communication, documentation and seismic instrumentation that developed throughout the Middle East during this period. Due to the relatively large amounts of instrumental earthquake data available for the 19th century (particularly from 1850 onwards), only those earthquake events for which macroseismic data are also available have been listed in the catalogue. The catalogue may be considered nearly complete for 19th century earthquake events of moderate magnitude or larger.

5.5.2 Distribution of historical earthquake activity

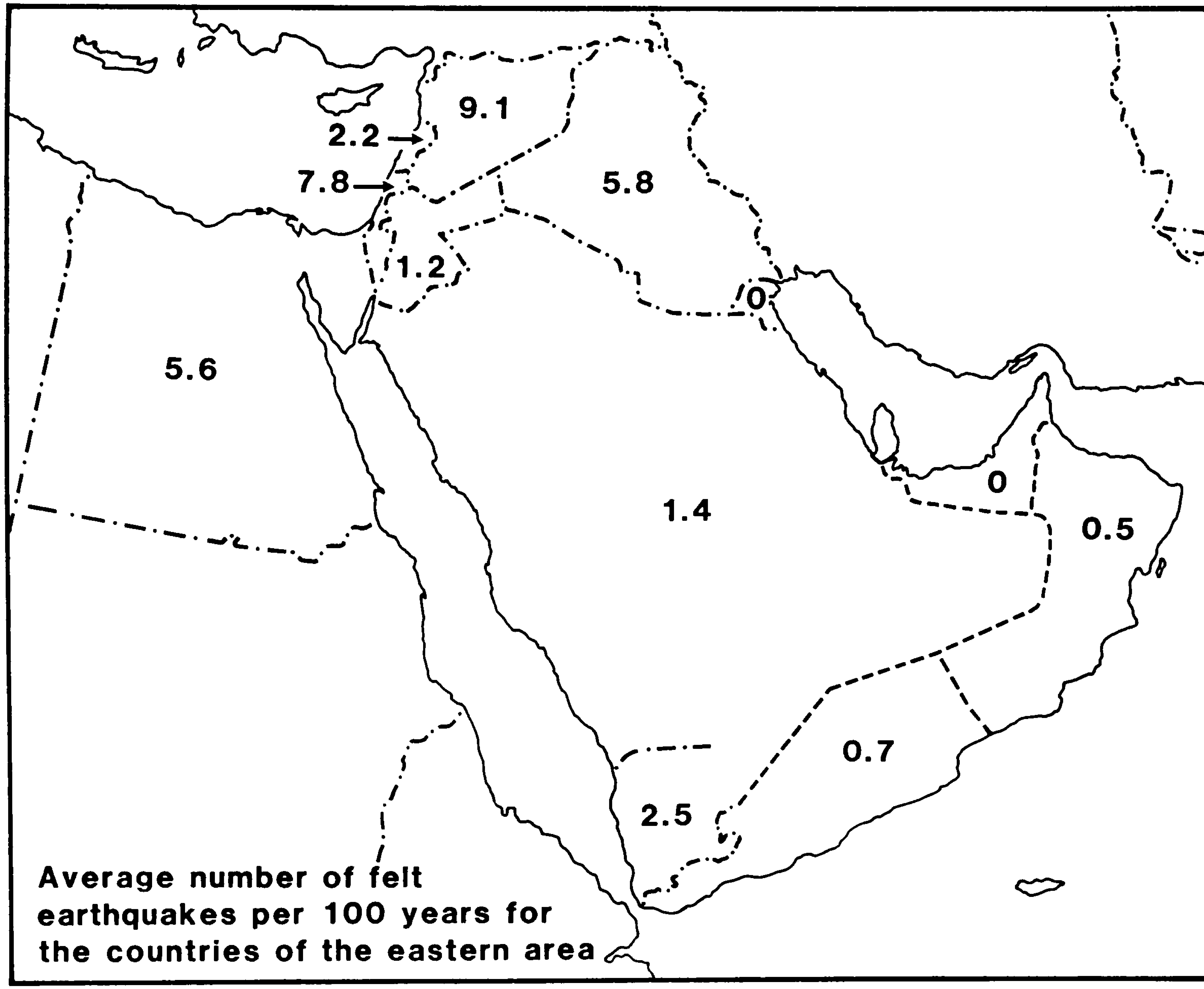
Although the historical catalogue is incomplete, the data available at present are sufficient to permit a general interpretation of the distribution of historical earthquake activity in the region.

When analysing the catalogue, it is important to be wary of the bias that can be introduced by historical centres of population. In order to reduce this, the present study aims to focus attention upon the seismicity of particular regions or countries, rather than upon individual cities. The advantage of such an approach is that it treats historical centres of population merely as "recording stations" for the large tracts of land (frequently uninhabited) that surround them. In this way, it is possible to gain an overall impression of the relative susceptibilities of different parts of the Middle East to earthquakes.

5.5.2.1 Inter-country analysis

Figure 5.3 provides a summary of the incidence of historical

Figure 5.3

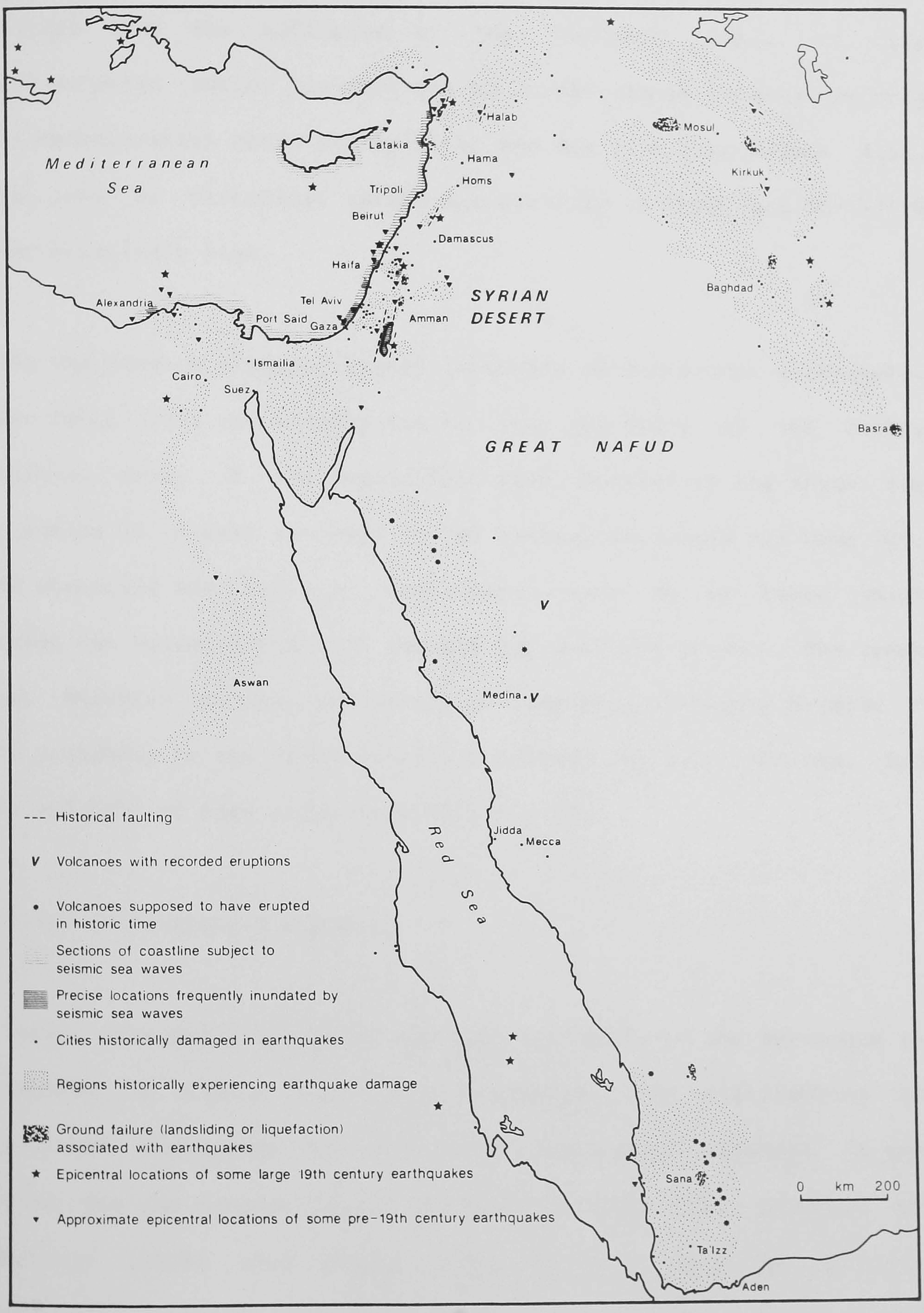


Average number of felt earthquakes per 100 years for the countries of the eastern area earthquakes in the region. For each country, the figure shows the average number of FELT earthquakes per 100 years, calculated using summations of earthquake activity taken from the oldest recorded event onwards. The figure shows generally higher incidences of earthquakes in those countries that border the Mediterranean Sea. This can, in part, be attributed to the occurrence of large earthquakes in the offshore tectonic zones of the eastern Mediterranean basin (see Figures 4.1 and 4.3). Earthquake incidence is particularly high in the Levantine countries, due to the additional effects of the Dead Sea rift. Earthquakes along the rift seem to be more frequent in the southern section (Israel) and northern section (Syria), than in the central section that passes through Lebanon. It is possible that the greater recorded historical seismicity of Syria and Israel is partly due to the presence of major historical centres of population in these countries (e.g. Jerusalem, Aleppo, Damascus and Antioch). However, Lebanon also has several important cities with a long and prosperous history. Coastal Lebanese cities such as Tripoli, Beirut and Tyre are sufficiently close to the rift valley to have recorded the occurrence of large earthquakes along the fault. Ba'albek was once an important Lebanese city, and is situated adjacent to the rift.

The highest rate of Middle Eastern earthquake incidence has been in Syria. This is probably due to the fact that the northern part of the country lies close to the point of intersection of the Dead Sea rift and the Anatolian fault systems (see Figure 4.2). Amiran (1952) has suggested that this is the most active onshore earthquake zone in the entire Middle Eastern region.

Figure 5.4

A summary of historical earthquake activity and associated hazards in the eastern area (1AD to 1899AD)



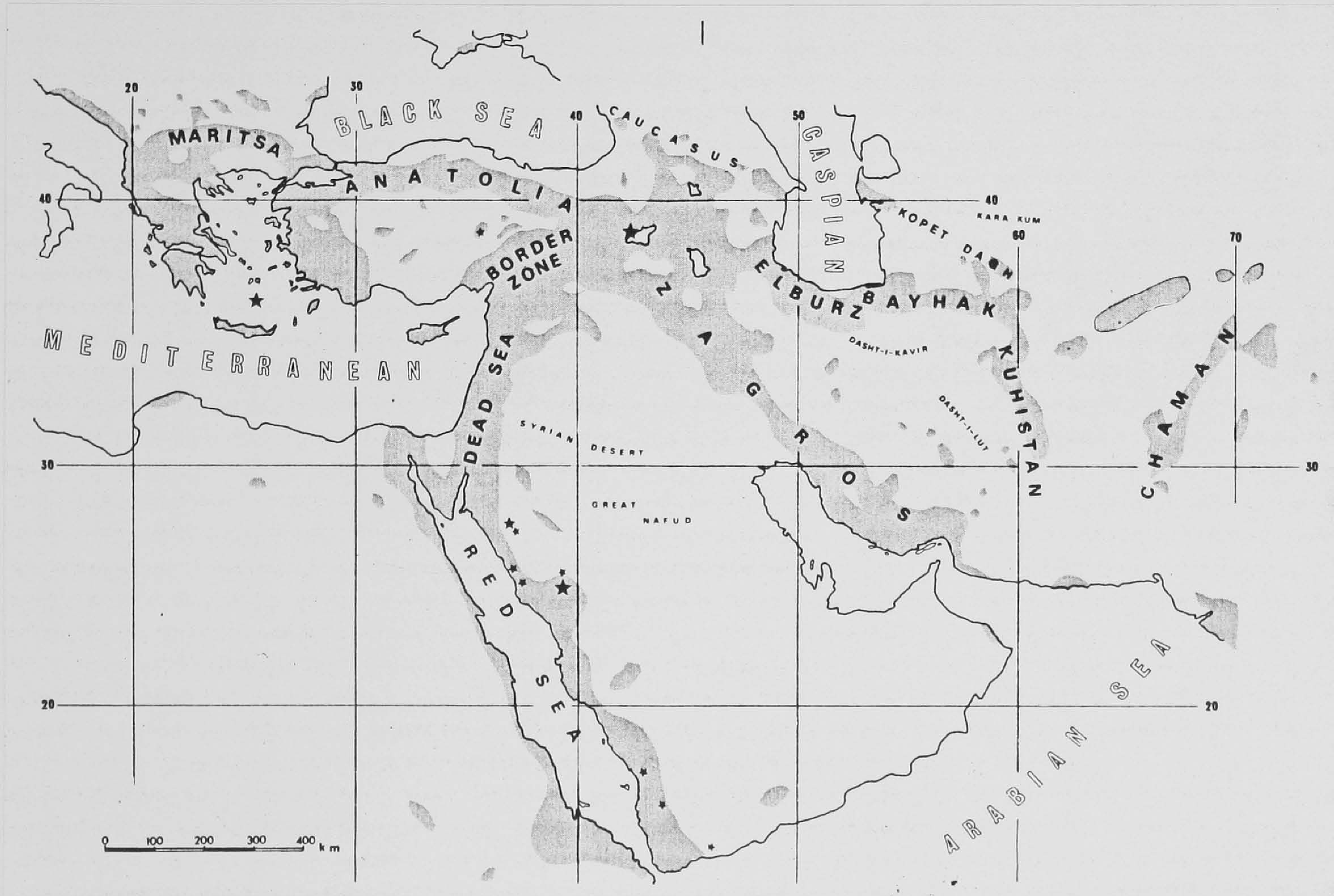
Although situated adjacent to the Dead Sea rift, Figure 5.3 shows that the incidence of earthquakes in Jordan has been lower than in the aforementioned countries. This is probably because Jordan is far removed from the influence of the tectonic zones of the Mediterranean basin. In contrast to Jordan, Egypt borders not only the Mediterranean basin but also the Red Sea rift (see Figure 4.2). The rate of historical earthquake activity in Egypt has therefore been relatively high.

Iraq has shown a slightly higher incidence of historical earthquakes than Egypt. This is probably due to its proximity to the active tectonic zones of the Zagros fold belt. Further to the south, the incidence of seismic activity in the Arabian Peninsula has been low. The countries most prone to earthquakes seem to be those which border the tectonic zones of the Red Sea and Gulf of Aden. The Yemen Arab Republic has been particularly vulnerable, probably because of its proximity to the triple junction between the East African, Red Sea and Gulf of Aden rifts (see Figure 4.2).

5.5.2.2 Intra-country analysis

A more detailed analysis of the data contained in the catalogue is presented in Figure 5.4. This summarises the distribution of historical earthquake activity (and associated hazards) in the region. The map compares quite favourably with that produced by Ambraseys (1978) (see Figure 5.5). However, there are important differences between the two maps, simply because the present catalogue focusses attention upon those areas in which earthquakes were FELT, rather than upon the epicentral locations of historical

Figure 5.5 Seismic activity of the eastern area (and adjacent regions) during the first 17 centuries AD



Shading shows epicentral areas of destructive or damaging events. Stars indicate volcanic eruptions.

After Ambraseys (1978, p.191)

events. Unlike Ambraseys' map, Figure 5.4 also attempts to show the distribution of earthquake-related hazards, including tsunamis and volcanic eruptions.

The overall impression given by Figure 5.4, is that earthquake hazard has been greatest in the areas bordering the major tectonic zones of the region (see Figure 4.2). Damage seems to have been particularly severe in alluvial areas lying adjacent to these tectonic zones. For example, the Nile delta, Jordan valley and Mesopotamian plain. The soft, unconsolidated (and often water-saturated) deposits of these alluvial areas make them particularly susceptible to earthquake ground motions. They serve to slow down the passage of earthquake shock waves, and to amplify them.

The areas in each country that, historically, have been most vulnerable to earthquake hazard, are as follows:

EGYPT

The catalogue shows that the majority of the large earthquakes that have affected Egypt were also felt in Greece, Turkey and the countries of the Levant. Few large events have caused damage in Egypt alone. This would seem to suggest that the source-area of the most destructive Egyptian events is the eastern Mediterranean basin, to the north of the country.

Earthquakes of this type have caused particularly heavy damage in the cities of the Nile delta (e.g. Alexandria, Cairo). The delta region is very vulnerable to large Mediterranean earthquakes, mainly due to its coastal location. In addition, the soft, unconsolidated deposits of the delta are sensitive to earthquake ground motions, and probably serve to amplify shock waves emanating from a distant earthquake source.

The delta region has also experienced considerable damage as a result of earthquakes in the Gulf of Suez and northern Red Sea. Historical events of this type are easily identified because they usually affect parts of Egypt, Saudi Arabia and southern Israel simultaneously. The historical catalogue would seem to suggest that violent shocks are much less common in the Red Sea than in the eastern Mediterranean basin.

The catalogue contains some records of earthquakes that affected the delta region of Egypt, but no other part of the Middle East. These are likely to have been earthquakes of moderate magnitude that originated along faults within the Nile cone. Events of this type are frequently associated with localised heavy damage in the delta.

The Nile valley is depicted in Figure 5.4 as a distinct linear zone that has experienced historical earthquake damage, whereas the regions to the east and west of it have not. It is highly likely that the reason for the prominence of the valley in historical earthquake reports, is the fact that for centuries it has been densely populated. Conversely the Eastern Desert of Egypt, situated between the River Nile and the Red Sea, has always been an area of very low population density. It is hardly surprising, therefore, that little earthquake damage has been recorded from this region despite its proximity to the Red Sea tectonic zone. All other considerations being equal, however, the Nile valley is likely to be particularly susceptible to earthquake ground motions because of the presence of thick soft alluvial deposits in the valley bottom.

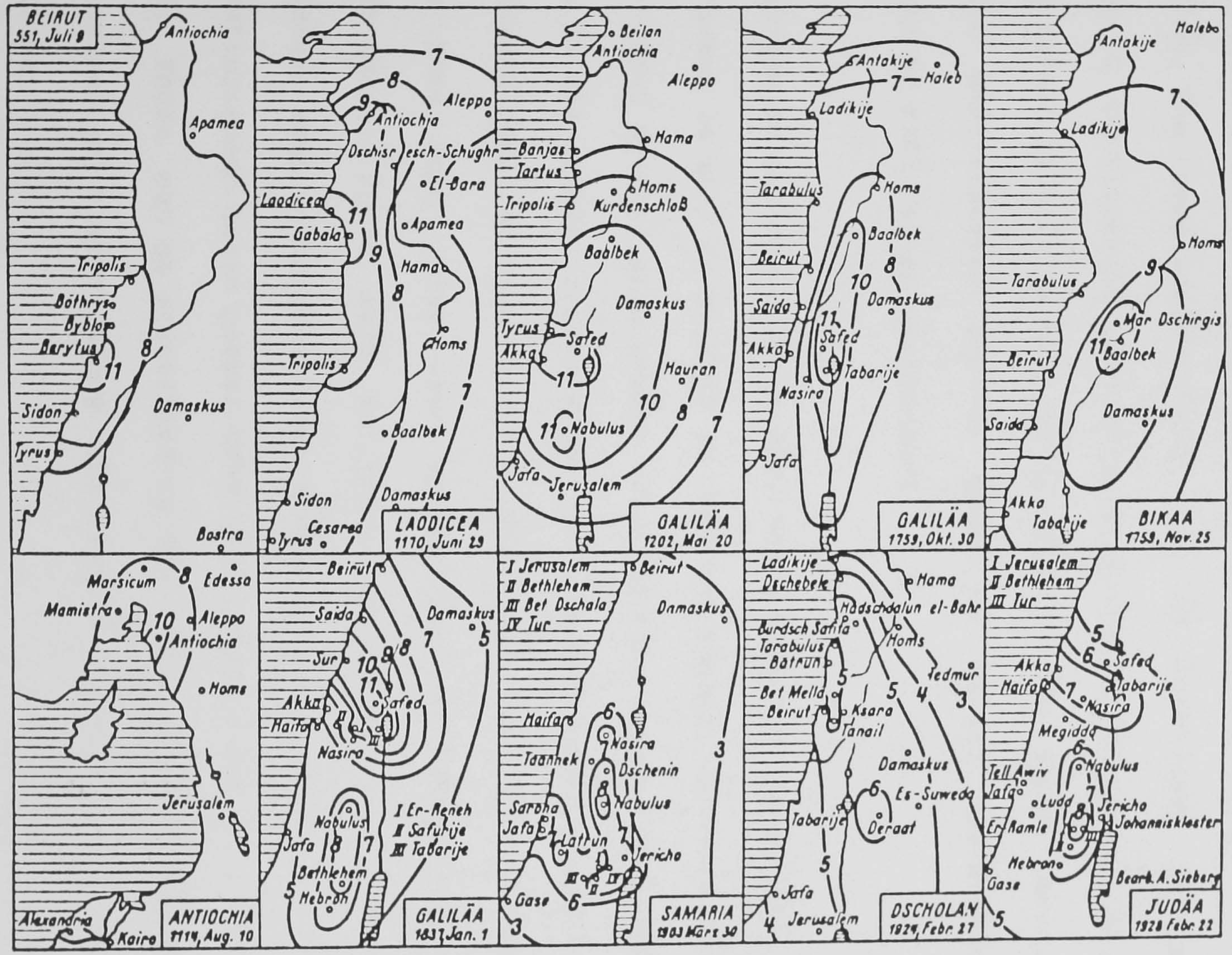
Sinai has experienced several destructive earthquake events, though records tend to be poor due to the low population densities found in this part of the region. Sinai is particularly susceptible to large earthquakes that are occasionally generated in the northern part of the Red Sea, at a point where the three rift systems of the Gulf of Suez, Gulf of Aqaba and Red Sea intersect (see Figure 4.2). St Catherine's Monastery, in southern Sinai, has provided some of the only records of historical earthquake damage for this part of the Middle East.

ISRAEL AND JORDAN

The majority of large onshore earthquakes (with epicentral intensities of IX or greater) in Israel and Jordan, have occurred along or adjacent to the Jordan rift valley. Figure 5.4 shows that the southern part of the rift (i.e. the Arava section), extending between Eilat (at the top of the Gulf of Aqaba) and the Dead Sea, has experienced less earthquake damage than the more northerly section between the Dead Sea and Lake Tiberias. This, however, could partly be attributable to the fact the Arava region has always been one of the the least densely populated parts of the rift valley.

The historical data highlight an interesting aspect concerning the distribution of damage caused by large earthquakes along the Jordan

Figure 5.6 Sieberg's (1932) isoseismals for 10 earthquakes in the Levant fracture region



As reproduced in Ben-Menahem (1979, Fig. 2) rift (i.e. the area violently shaken by the earthquakes is often elliptical in form, the major axis of the ellipse running roughly parallel to the rift). Severe ground motions and destruction are frequently experienced along the length of the Jordan valley, without propagating very far away from it in an easterly or westerly direction. The isoseismals of the 1759 AD earthquake in Galilee provide a particularly good example of this (see Figure 5.6). As a direct result of this pattern of attenuation of shock waves, the southern Mediterranean coastal plain of Israel has seldom been affected by rift valley earthquakes.

In addition to onshore earthquakes, the historical catalogue shows that Israel is also vulnerable to offshore events. Evidence for this is provided by the large number of earthquake reports that refer to damage in the coastal region only, often accompanied by observations of tsunamis (see Section 5.7.1). The most destructive offshore events have been those with epicentres relatively close to the Israeli shore. These tend to cause damage along a relatively restricted section of coastline. However, large magnitude events in the Mediterranean basin proper have also caused severe damage in Israel. These can be identified by the widespread destruction that they cause in cities along the entire Levant and Egyptian coastlines.

The historical catalogue provides considerable evidence concerning the influence of subsoil in controlling the distribution and severity of damage experienced in Israel and Jordan during earthquakes. For instance, the deep alluvial fill of the Jordan rift valley has often served to increase the destructive effect of earthquakes. Outstanding in the records of historical earthquake damage along the rift, are the ancient cities of Jericho (founded on alluvium) and Tiberias (founded on steep slopes and alluvial fill). Much of the severe earthquake damage experienced in the cities of the Israeli coastal plain, can also be attributed to poor subsoil conditions that have served to aggravate earthquake ground motions. An in-depth discussion of the effects of subsoil on earthquake hazard distribution in Israel will be presented in Chapter 8.

LEBANON AND SYRIA

Records of earthquake damage in Lebanon are not as good as those for Israel and Syria. Once again, however, most onshore earthquake activity seems to have been associated with the rift valley. The northern part of the Lebanese rift (Beqa'a valley) has experienced a higher incidence of historical earthquake activity than the southern part (Litani valley). Numerous large earthquakes have occurred along the Beqa'a valley, including those of 565, 991, 1201, and 1802 AD. These earthquakes were often documented because of their effect upon the Lebanese town of Ba'albek, or upon Homs in Syria. It is highly likely that many of the historical earthquakes that have affected Damascus (Syria) were generated along the Lebanese section of the rift.

Due to the fact that much of the interior is mountainous, many of the major cities in Lebanon are situated along the coast. Founded for the most part upon soft, saturated deposits of the coastal plain, the Lebanese coastal cities have been particularly vulnerable to damage induced by offshore earthquakes. This is also the case for the coastal cities of Syria, which have experienced heavy damage on numerous occasions as a result of earthquakes in the eastern Mediterranean basin or Gulf of Iskenderun. Cities such as Tyre, Beirut, Tripoli, Latakia and Banias feature heavily in the catalogue.

As mentioned in Section 5.5.2.1, Syria seems to have experienced a higher incidence of earthquake activity than any other Middle Eastern country. Antakya (Antioch), once the capital of Syria and one of the great cities of the Mediterranean ancient world, has been repeatedly destroyed by terrible earthquakes. Figure 5.4 shows that the distribution of historical earthquake damage in Syria essentially follows the Syrian section of the rift valley. From Hama, it stretches north along the Orontes valley to Antakya, and east to Halab (Aleppo). The Border Zone (north of Antakya, along the Turkish border) has also experienced a great deal of historical earthquake activity.

Amiran (1952) has suggested that the most active onshore tectonic zone in the entire Middle East is the area around Iskenderun and Antakya in northern Syria/southern Turkey. As mentioned in Section 5.5.2.1, it is here that the northern end of the rift valley interacts with the East Anatolian fault system. The catalogue shows that many large earthquakes have occurred in this zone, often followed by long destructive aftershock sequences lasting several months. Earthquakes of this type have caused widespread damage throughout Syria.

On Figure 5.4, the Syrian Desert stands out as a region for which there are no available records of historical earthquake damage. Similarly the Great Nafud to the south has produced no literary evidence of a seismic history. It is possible that the apparent aseismicity of these areas is simply a reflection of the absence of sedentary centres of population within them. However, as Ambraseys (1978) has shown, the fact that there are no records of earthquakes simultaneously affecting the populated areas surrounding these wildernesses, would seem to suggest that the absence of earthquakes is a real one.

IRAQ

The areas experiencing historical earthquake damage in Iraq are restricted to the eastern and north-eastern parts of the country, adjacent to the Zagros fold belt. Within the Zagros, most earthquake damage has been concentrated in a zone lying east of Mosul and Kirkuk (and south-west of the main Zagros thrust). Historical reports show that many of the earthquakes in this area have been accompanied by short aftershock sequences.

Earthquakes originating in the Zagros have frequently inflicted major damage on cities of the Mesopotamian plain to the south-west (e.g. Baghdad, Basra, Al Kut and Ahvaz). Situated on alluvial deposits that are often water-saturated, these Iraqi cities are very sensitive to strong earthquake ground motions.

SAUDI ARABIA AND THE YEMEN REPUBLICS

Saudi Arabia and the Yemen Republics lie adjacent to the Red Sea tectonic zone. Records for this part of the region are generally not as good as those for the countries to the north, and extend only as far back as the beginning of the Arabic era in the 7th century AD. Earthquakes in Arabia have seldom attracted attention outside the area, and this has hindered the reporting of events in regional catalogues.

Figure 5.4 shows that documented earthquake activity is restricted to the western margin of the Arabian peninsula. Violent earthquakes in the region seem to be rare, and the historical data suggest that coastal districts of Saudi Arabia and the Yemen Republics have only occasionally been affected by large Red Sea earthquakes (affecting the coast of Africa at the same time). The majority of historical seismicity seems to have been generated by onshore faults. It is probably no coincidence that the areas experiencing earthquake damage coincide with centres of volcanic activity (see Figure 5.4). Many of the shocks reported for the Yemen Arab Republic have been of medium magnitude, and were followed by long aftershock sequences. According to Ambraseys and Melville (1983), this is a common characteristic of earthquakes associated with volcanism.

Figure 5.4 shows that earthquakes have caused damage in the northern and southern sections of the western part of the Arabian peninsula, but that damage has been restricted in the central section. This is in general agreement with the findings of Al-Noury and Ali (1986), who have mapped earthquake hazard in the region. They conclude that the seismic hazard potential for the central coastal area is moderate, but that it is high for the northern and southern provinces.

THE GULF STATES

Away from the active tectonic zones of the Red Sea and Gulf of Aden, the central and eastern parts of the Arabian peninsula seem to be largely aseismic, though the historical documentation for these areas is extremely poor. Minor historical seismicity has been recorded for the Gulf region, including an earthquake that was strongly felt in Bahrain in 1426 AD. The coastal regions of Oman have very occasionally been affected by large offshore earthquakes (e.g. March, 1884 AD), or by earthquakes originating in south-western Iran. However, these earthquakes have not caused particularly heavy damage.

5.6 HISTORICAL SEISMICITY OF THE MIDDLE EAST (Western part)

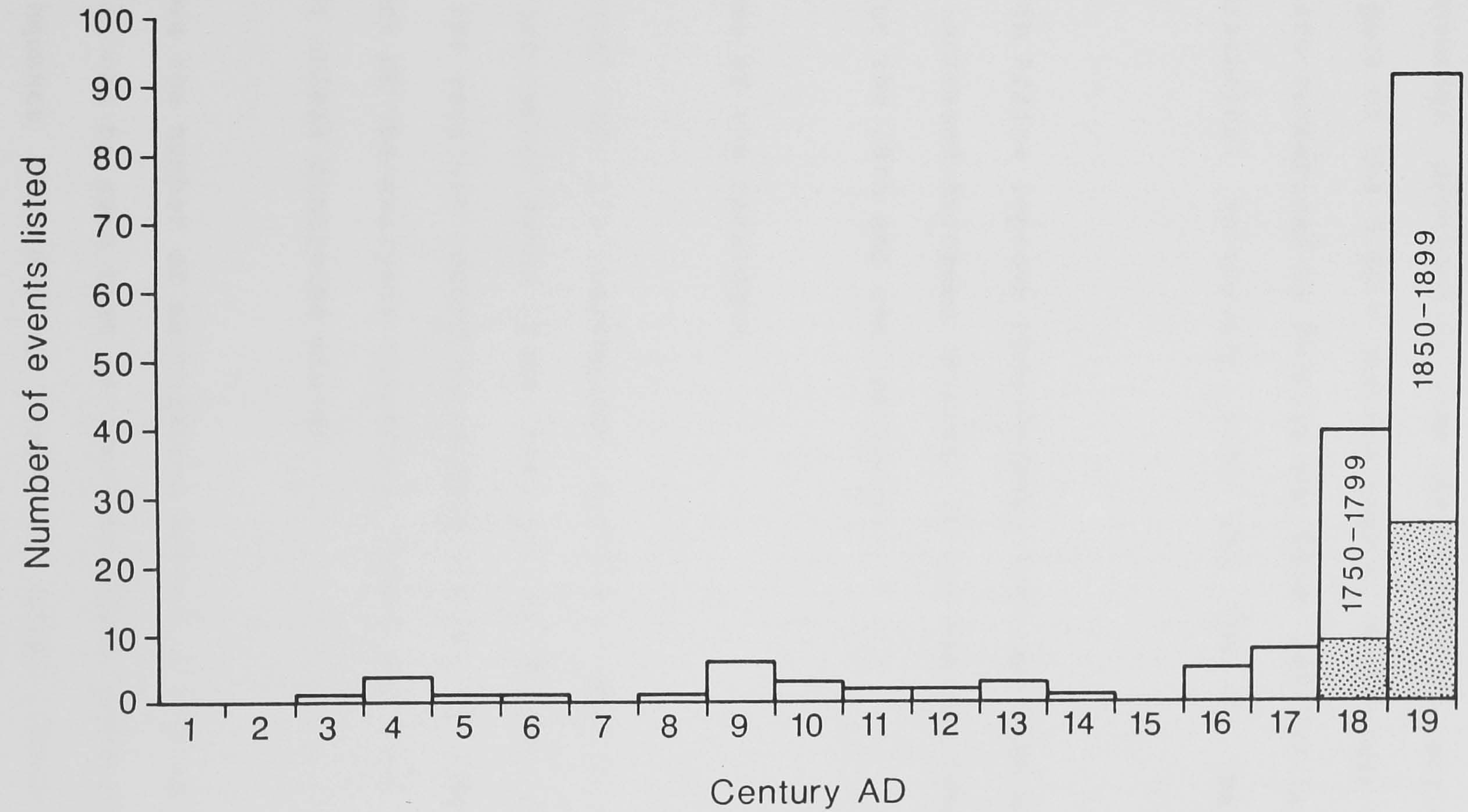
The early record of historical earthquake activity in the western part of the region is very poor, and does not extend back over as long a time period as that observed for the eastern part. This is probably due to bad documentation in the countries of North Africa.

The main reason for poor historical documentation in North Africa, is that the region has not seen the rise of great sedentary civilizations similar to those that developed in the countries of the eastern Mediterranean. Other reasons include:

- Many of the early records for the eastern Mediterranean derive from Biblical sources. These obviously do not exist for North Africa;

Figure 5.7

Number of earthquake events listed in Part II of the catalogue per century AD



- Greek and Roman records provide much of the historical data for the Levantine countries and Egypt. These records are very poor for the countries of North Africa;

- Historical coverage provided by Arab chroniclers is very scanty for the western part of the Middle Eastern region. Those data which are available are summarised by Poirier and Taher (1980), in their catalogue of historical seismicity from the 7th to the 18th centuries.

Records for North Africa improve considerably from the 16th century onwards, due to increased European interest in the region. They are extremely good for the 18th and 19th centuries.

5.6.1 Completeness of the catalogue

There are a total of 171 earthquake entries in Part II of the catalogue. Only one record dates from the period before Christ. After Christ, the earliest record dates from 262 AD. All the dates given in this part of the analysis therefore refer to the period after Christ (AD) unless otherwise stated.

Figure 5.7 shows the number of earthquakes listed in the catalogue per century AD. It can be seen that up until the 16th century, the number of earthquakes recorded is extremely small. There are no entries whatsoever for the 1st, 2nd, 7th and 15th centuries, though six records exist for the 9th century. It is highly likely that these fluctuations in the early record are merely a reflection on the poor quality of the record, and therefore not of any tectonic significance. It is interesting to note that there is no evidence whatsoever of a peak in earthquake activity for the 12th century AD, similar to that observed in Part I of the catalogue (see Section 5.5.1 and Figure 5.2).

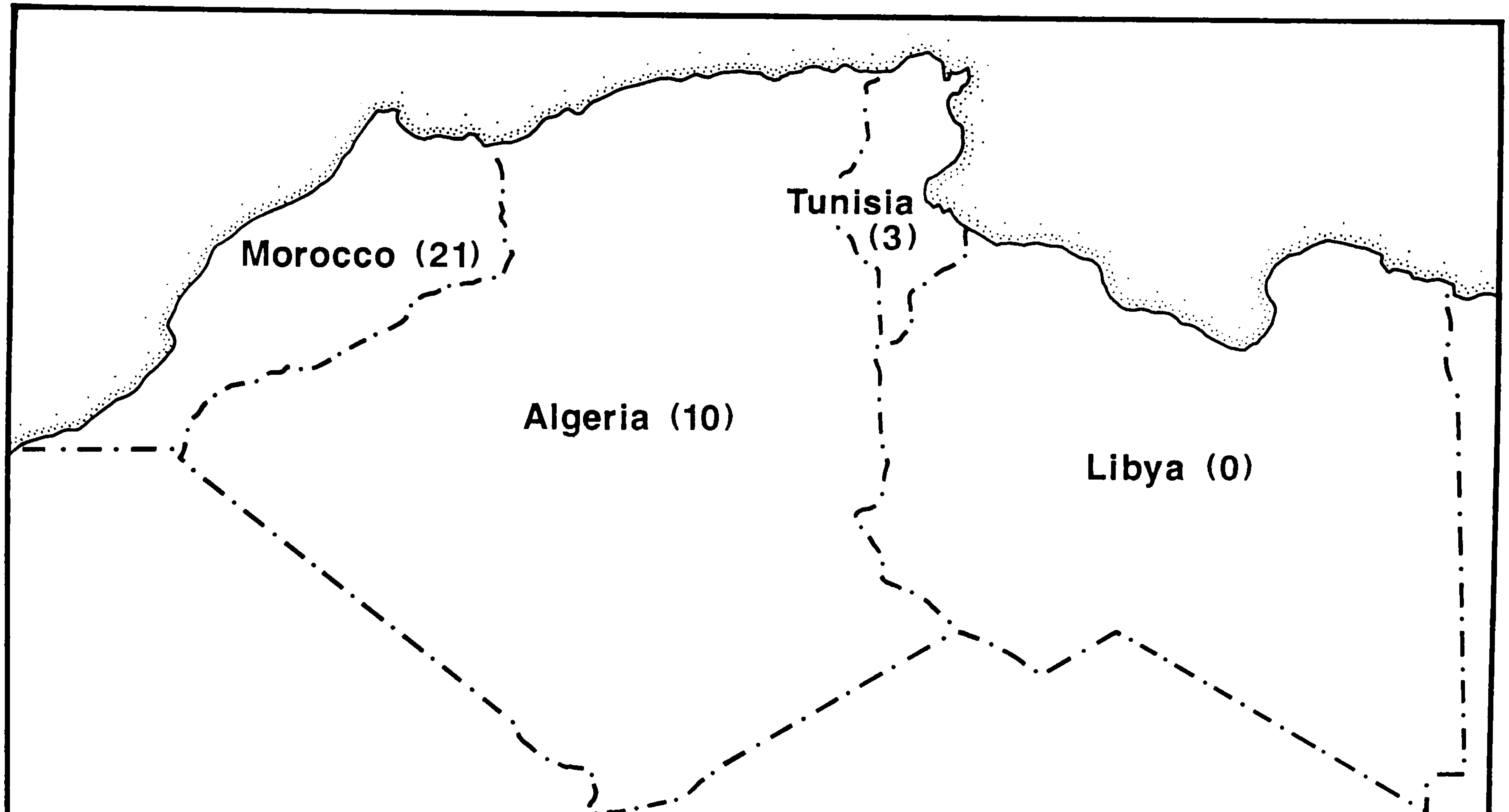
From the 16th century onwards there is an increase in the number of events listed in the catalogue. This increase is gradual at first, but becomes very marked in the 18th and 19th centuries. The most likely reason for this apparent upsurge in activity is the improved means of communication and documentation that developed throughout North Africa during this period. There is, however, some suggestion of a real upsurge in seismic activity during the latter half of the 18th century. A possible explanation for this is given in Section 5.6.2.1.

Records for the 19th century are extremely good due to European influence in the area, and also due to the introduction of seismic instrumentation towards the turn of the century. Once again, only those 19th century earthquakes for which macroseismic data are available have been included in the catalogue. The catalogue for the 19th century may be considered comprehensive for earthquake events of moderate magnitude or larger.

5.6.2 Distribution of historical earthquake activity

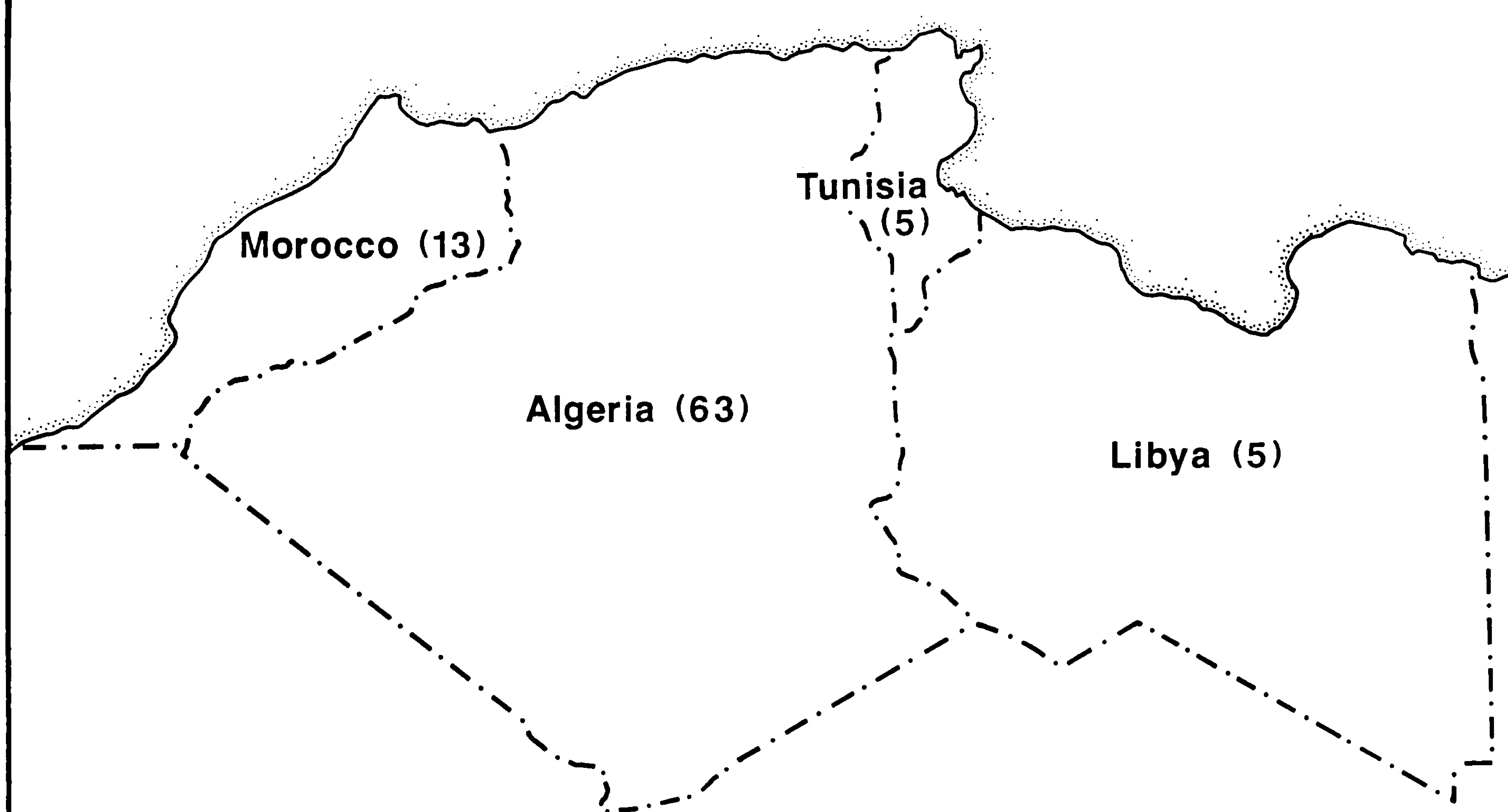
The same principles have been applied in the analysis of this part of the catalogue as were used to analyse Part I. These are outlined in Section 5.5.2.

Figure 5.8



Number of earthquakes felt in the countries of the western area during the 18th century

Figure 5.9



Number of earthquakes felt in the countries of the western area during the 19th century

5.6.2.1 Inter-country analysis

Although the historical catalogue is obviously incomplete, the data available at present are sufficient to permit a general interpretation. Figures 5.8 and 5.9 provide a summary of the incidence of historical earthquakes in the region. For each country, the figures show the average number of earthquakes FELT during the 18th and 19th centuries (i.e. for the historical time period during which records for the region are reasonably comprehensive). The figures show higher incidences of earthquakes in Morocco and Algeria than in Tunisia and Libya. This is probably due, in part, to the influence of the Atlas and Rif tectonic belts of north-west Africa (see Figure 4.6).

The Atlas mountain range passes through Morocco, Algeria and Tunisia. Although it is seismically active along its entire length, the 19th century historical data suggest a much higher rate of seismic activity in Algeria than that observed in either Tunisia or Morocco (see Figure 5.9). This pattern of activity is supported by the 20th century seismic data for the region (see Section 4.5.2 and Figure 4.4). One possible reason to explain this is that aseismic deformation can more easily take place in the "unconfined" western and eastern extremities of the Atlas mountain chain, than in the central section.

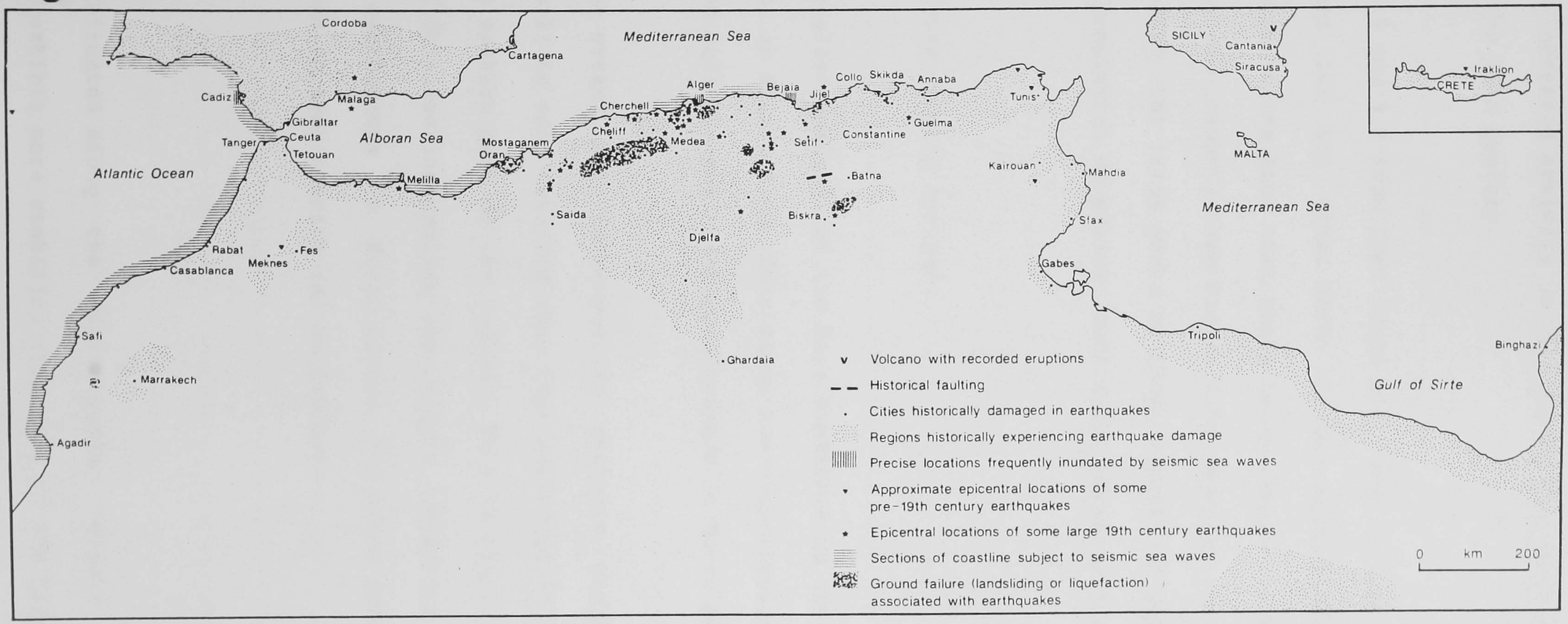
The 18th and 19th century data suggest that Morocco is more vulnerable to earthquakes than Tunisia (see Figures 5.8 and 5.9). This is probably because in addition to its active onshore tectonic zones, Morocco is affected by large magnitude earthquakes originating offshore along the Azores-Gibraltar ridge. Many historical earthquakes of this type have caused simultaneous damage across large parts of Morocco, Portugal and Spain.

Although there are offshore tectonic zones east of Tunisia (see Figure 4.6), the catalogue suggests that these have not been as active as the Azores-Gibraltar ridge. Large magnitude earthquakes have occured close to Sicily and Italy, but there is no evidence of these having affected the Tunisian mainland. This is also the case as far as large earthquakes originating in the eastern Mediterranean basin are concerned.

During the 18th century, the number of earthquakes recorded in Morocco was considerably greater than that in Algeria (see Figure 5.8). The historical catalogue shows that this apparent fluctuation in the "normal" distribution of seismic activity in North Africa, was not due to increased activity in the Atlas and Rif mountains of Morocco relative to that in Algeria. It was, in fact, due to a period of increased activity in the offshore region along the Azores-Gibraltar ridge. The Atlantic coastal cities of Morocco (from Agadir to Cape Bon) were particularly badly affected by earthquakes at this time, as were cities lying along the southern shorelines of Spain and Portugal. The Azores islands also experienced considerable seismic and volcanic activity during the 18th century.

Atlantic earthquake activity during the 18th century came to a head on November 1, 1755, with the Great Lisbon Earthquake. This caused extensive damage across large parts of Portugal, Spain and Morocco. A large number of aftershocks occurred throughout November of that

Figure 5.10



A summary of historical earthquake activity and associated hazards in the western area (1AD to 1899AD)

year, and increased activity in the region continued into the early parts of the 19th century.

Figures 5.8 and 5.9 show that there are fewer earthquake records for Libya than for any other North African country. This is probably attributable to the fact that there is an absence of major tectonic units in the country (see Figure 4.6). However, it should also be borne in mind that large parts of Libya consist of desert areas with very low population densities. Such areas preserve a poor historical record.

5.6.2.2 Intra-country analysis

A more detailed analysis of the data contained in the catalogue is presented in Figure 5.10. This shows the distribution of historical earthquake activity and associated hazards in North Africa.

To a large extent, the intra-country analysis presented in this section will be more detailed than that presented in Section 5.5.2.2 (for the eastern part of the region). This is simply because of the wealth of detailed information that exists concerning 18th and 19th century earthquakes in North Africa. The areas most vulnerable to earthquakes in each country are as follows:

MOROCCO

Although situated along the Mediterranean seismic belt, Morocco seems to exhibit more stability than many of the other countries in this zone. The historical catalogue shows that earthquakes have occurred in the country less frequently, and have been less violent than those observed in neighbouring countries (i.e. Spain, Portugal and Algeria). As a consequence, the historical data for Morocco are not as detailed as those for Algeria.

Figure 5.10 shows that two main zones have historically experienced earthquake damage in Morocco:

a) The coastal zone

Both the Mediterranean littoral region and that which borders the Atlantic Ocean have experienced considerable earthquake damage. Important Moroccoan cities such as Tetouan, Tanger, Rabat, Sale, Casablanca and Safi have repeatedly been affected. They are particularly sensitive to earthquake ground motions because they are situated upon soft alluvial deposits of the coastal plain.

The soft sediments of the coastal plain are particularly sensitive to the predominantly long-period ground motions associated with distant earthquake events. This is important because, in the vast majority of cases, the epicentres of earthquakes that have affected the littoral region seem to have been offshore. In the case of larger events, proof of a submarine origin is provided by the fact that heavy damage was simultaneously experienced along the coasts of Morocco, Spain and Portugal (e.g. in the Lisbon earthquake of November 1, 1755).

It is extremely difficult to assign precise epicentral locations to historical submarine earthquakes, and therefore few are marked on

Figure 5.10. Those which are shown have been determined by Udias *et al.* (1976). They managed to overcome the locational problem for some large historical submarine events, by comparing the distribution of historical earthquake effects with those of more recent events whose epicentres have been instrumentally determined.

In general it would seem that the largest submarine events have occurred along the Azores-Gibraltar ridge. This zone has been characterised by the occurrence of large earthquake events (of magnitudes >7.0) that have affected Morocco and the southern Iberian peninsula. The catalogue shows that these very strong shocks occur sporadically, separated by long periods of quiescence. Many of the shocks have been followed by long aftershock sequences. For example, strong tremors were felt for almost a month after the Lisbon earthquake.

In contrast, the submarine tectonic zones off the north coast of Morocco (in the Alboran Sea) seem to have been characterised by more regular seismic activity. This has affected historical centres of population such as Tanger, Ceuta, Gibraltar and Tetouan. The historical earthquakes in the region have only been felt over relatively small areas, suggesting that they are of lower magnitudes than those experienced to the west of Gibraltar. Only very occasionally do events in the Alboran Sea seem to have been large enough to affect both Morocco and Spain (e.g. October 9, 1680). Large magnitude earthquakes of the type generated along the Azores-Gibraltar ridge, seem to be of very rare occurrence in this area.

As far as the islands off the Moroccan coastline are concerned, there are historical records of earthquake damage in the Balearics. For example, the earthquakes which affected Minorca on October 20, 1654 and Majorca on March 24, 1721. For the Atlantic region, the catalogue contains numerous reports of earthquakes in the Azores (e.g. July 9-10, 1757 and August 11, 1810). The reports are unfortunately not particularly detailed, probably because the population of the Azores was very low between the 16th and 19th centuries (Udias _et al_., 1976). Strong shocks have also occasionally been reported from the Canary and Cape Verde Islands. Many of these have been related to volcanic activity (e.g. March 20, 1810).

b) The interior zone

The second zone in Morocco that has experienced earthquake damage lies along the Atlas fold belt. It is quite poorly defined by the historical records, probably due to the absence of large centres of population in the mountainous interior of the country. An indication of the true nature of the hazard in the Atlas region of Morocco, is provided by the fact that its three major centres of population (Marrakech, Fes and Meknes) have all been damaged by earthquakes on numerous occasions.

Away from the active tectonic belts of the interior, and from the influence of offshore tectonic zones, there are no records of historical earthquake damage in southern and eastern Morocco. It is highly likely that these areas are largely aseismic, though reporting of historical earthquake events may have been hindered by the low population densities found in these parts of the country.

ALGERIA

Of all the countries in North Africa, the most comprehensive records exist for Algeria. Records for the 19th century are particularly good, and contain precise details of areas affected and losses experienced.

Figure 5.10 shows that historical earthquake damage has been confined to the northern parts of the country. It has occurred in those areas lying along and adjacent to the Atlas fold mountains. The data contained in the catalogue suggest that the northern part of Algeria can be divided into two zones, each with a different rate of earthquake activity:

a) Tell Atlas region

The Tell Atlas border the coastline of Algeria. The historical records suggest that they are the most active seismic zone in North Africa. Figure 5.10 shows that the vast majority of known historical earthquake epicentres (in North Africa) are located in the Tell Atlas. Within the region, the mountain chains of the Biban, Hodna, Babors and la Medjerda have all been important epicentral areas, as have the Massif de l'Ouarsenis and the Dahra mountains. A large number of towns in the region have experienced repeated earthquake damage (e.g. Oran, Mostaganem, Mascara, Medea, Blida, Alger, Constantine and Setif).

b) Saharan Atlas region

The Saharan Atlas lie to the south of the Tell Atlas. Taking into consideration the fact that the Saharan Atlas have not been as densely populated as the Tell Atlas, there can still be little doubt that the historical seismicity of this region has been less than that experienced further to the north.

South of the Saharan Atlas, there is no historical evidence of earthquake activity in southern Algeria. However, this could partly be attributed to the fact that the population densities in the southern part of the country have always been very low.

The catalogue shows that most of the earthquakes in the Atlas mountains of Algeria have been localised events, frequently with numerous aftershocks. They have been responsible for causing quite intensive damage (intensities greater than VIII are very common in the historical reports) over relatively small areas. These observations would seem to suggest that the earthquakes were shallow seismic events that originated along faults in the Atlas mountains. This is substantiated by the fact that few of the Algerian earthquakes were felt in adjacent countries (i.e. Morocco or Tunisia).

Unlike Morocco, Algeria has not experienced many large offshore earthquakes. Large submarine events seem to be of rare occurrence in the Mediterranean Sea to the north of the country. This is reflected by the absence of historical reports recording simultaneous earthquake damage in Algeria and Spain/France/Italy. Events of this type that have occurred have originated close to the Algerian coast. As a result, they have caused heavy damage in the Algerian coastal region only. One such earthquake occurred on August 21, 1856. The epicentre of this event probably lay several kilometres north of Jijel (see Figure 5.10). The earthquake was extremely severe and was felt in Algeria, France, Minorca, Sardinia and Italy. However, widespread destruction was caused along the Algerian coast only.

An interesting observation concerning some of the large onshore events in Algeria, is the pattern of propagation of shock waves away from epicentral regions. The historical catalogue shows that the macroseismal areas associated with large Algerian earthquake events have frequently been elongated in a east-west direction. For example, in the earthquake of December 3, 1885, "the shock was largely felt in a triangular area between Ghazaoue and Collo (800km of coastline), and Ghardaia (400km inland)". The large Algerian earthquake of January 2, 1867, also demonstrated a much greater latitudinal attenuation of earthquake shock waves than longitudinal.

This can possibly be explained by the fact that the major tectonic structures and physical relief of Algeria have an east-west trend. These could therefore exert a "channelling" influence upon shock waves (similar effects were described for the Jordan rift valley in Section 5.5.2.2). Indeed, Richter (1959) has remarked that isoseismals are often elongated parallel to structural trends. The implications of this for earthquake hazard in Algeria, are that the effects of earthquakes in the Atlas will essentially be confined to the northern parts of the country.

A final observation drawn from the catalogue, concerns the influence of ground conditions on the severity of shaking experienced during earthquakes in Algeria. One part of the country that features very prominently in historical earthquake reports is the Cheliff valley. The thick alluvial deposits of this valley make it particularly sensitive to earthquakes originating in the Tell Atlas. The vulnerability of this part of Algeria was re-emphasised by the El Asnam earthquake of October 10, 1980. This event, which was the largest in the Atlas since 1790 (Ambraseys, 1981), caused extensive damage in the central part of the Cheliff valley.

For the same reason, cities such as Oran, Skikda, Alger, and Annaba (situated on sediments of the coastal plain) have also repeatedly suffered heavy earthquake damage. In the October 9, 1790 earthquake at Oran, the worst affected part of the town was that situated on low-lying alluvial ground.

TUNISIA

Figure 5.10 shows that the areas experiencing historical earthquake damage in Tunisia are largely restricted to the northern half of the country, as well as to the eastern coastline. Most historical earthquakes in the country seem to have been extremely localised events that were not felt over particularly large areas. For example, the earthquake that affected Gabes in June, 1881 had a macroseismal area with a radius of 50km. Large earthquakes in the country seem to be extremely rare, and the only one listed in the catalogue is that which probably took place on December 3, 856. This caused extreme damage in Tunis and its dependencies, killing 45,000 people (estimate to be treated with caution).

The majority of historical earthquakes in Tunisia seem to have originated onshore along the Atlas fold belt. However, it is likely that some of those that have affected the eastern coastline of the country were of submarine origin. For example, that of October 5, 1750, which shook the Tunisian coast from Sfax to Cape Bon. In addition, the country has occasionally been affected by some of the very large earthquakes that originate in the eastern Mediterranean basin. For example, an earthquake occurred off the coast of Alexandria (Egypt) on July/August 8, 1303. This caused widespread damage in the eastern Mediterranean, but also affected Tunisia.

The historical record would seem to suggest that Tunisia is not affected to any significant degree by large Sicilian or Italian earthquakes. Similarly, the only large Algerian earthquakes to have affected the country have been those with epicentres very close to the Algerian-Tunisian border. There is no historical evidence of earthquakes in southern Tunisia.

LIBYA

The available historical earthquake data for Libya are extremely scanty. Figure 5.10 shows that few parts of the country have experienced earthquake damage. This reflects a general absence of particularly active onshore tectonic zones in the country.

Historical earthquake damage has mainly been confined to the north of the country. This is probably due to the combined effect of minor onshore tectonic zones (see Figure 4.6), and the offshore faults situated in the Gulf of Sirte. The largest Libyan earthquake listed in the catalogue is one that affected the northern coastline of the country in 1183, badly damaging Tripoli and killing approximately 20,000 people. Kebeasy (1981) considers this earthquake to have had a magnitude approaching 8.0.

Of those areas affected by earthquakes in northern Libya, the highest incidence of damage has been in the ancient region of Cyrenaica in the north-east. This region is fringed by the Al Jabal Al Akhdar uplift (see Figure 4.6), which has undoubtedly generated some of the earthquakes that have affected the area. In addition, the north-eastern part of the country has (on very rare occasions) been affected by minor earthquakes originating near Siwa Oasis in the Western Desert of Egypt (e.g. in 221 BC and 1811 AD).

The historical record suggests that northern Cyrenaica (and other parts of the littoral region of Libya), are also vulnerable to ground shaking induced by large magnitude earthquakes in the eastern Mediterranean basin. This is supported by Sieberg's (1932) maps, which show that events of this type have affected the north-eastern part of the country. The catalogue lists the following eastern Mediterranean events that affected the Libyan coastline:

AD 262 - affected Asia Minor and Libya;

July 21, 365 (ML 7.7) - epicentre close to Knossos, south-west Crete;

October 11, 367 (ML 6.7) - epicentre close to Cyprus;

July 9, 551 (ML 7.8) - epicentre off the coast of Beirut, Lebanon;

July/August 8, 1303 (ML 7.6) - epicentre off the coast of Alexandria, Egypt;

February 16, 1810 (ML 7.8) - epicentre in the Sea of Crete;

June 24, 1870 (ML 7.2) - epicentre off the coast of Alexandria, Egypt.

It is interesting to note that with the exception of the event of 367 AD, all these earthquakes had magnitudes greater than 7.0 (the magnitude of the 262 AD event is unknown). Obviously, it is only the very large eastern Mediterranean earthquakes (with relatively long recurrence intervals) that have affected the Libyan coastline.

Finally, the catalogue shows that the Fezzan area of south-west Libya has experienced earthquake activity on rare occasions (see Figure 5.10). The earliest recorded shock was in 704 AD, and destroyed many towns and villages. A larger event occurred on August 5, 1853. These two earthquakes are the only historical events that have been recorded for southern Libya. It is highly likely that the remainder of the southern part of the country belongs to the seismically stable Sahara block.

5.7 HAZARDS ASSOCIATED WITH EARTHQUAKES

A variety of natural hazards have been associated with earthquakes in the Middle East. The historical data that are available concerning these are listed in the catalogue (Parts I and II), and summarised in the indexes of hazards (Appendices A3 and B3) and in Figures 5.4 and 5.10.

5.7.1 Earthquake-related hazards in the Middle East (Eastern part)

Earthquakes are generated along faults. It is therefore of no surprise to find that some historical earthquake records include descriptions of ground FAULTING, though these are by no means common. Some of the best descriptions refer to the Dead Sea region. For example, the earthquakes of 31 BC and AD Jan 18, 746; Jan 14, 1546; Jan 1, 1837. The faulting seems to have been confined to the more central parts of the rift valley.

It is highly likely that surface faulting is of more common occurrence than the historical data show. The records are probably poor simply because faulting has attracted less attention from historians and chroniclers, than the damage inflicted by earthquakes upon centres of population.

Ground failure of one sort or another has frequently accompanied Middle Eastern earthquake events, and served to increase the severity of earthquake impact upon certain towns and cities. The most vulnerable areas are those underlain by alluvium, particularly when:

a) The alluvium is on the side of a hill and may therefore result in landsliding when shaken;

b) Groundwater is close to the surface, so that the alluvium can be subject to liquefaction and flow when shaken.

LANDSLIDING has often been triggered by large earthquakes along the Jordan rift valley. For instance, the earthquakes of 1250 BC and Jan 14, 1546 AD triggered landslides in the Lisan marl formation of the rift valley. The slumped material blocked the River Jordan for several days causing flooding. The Lisan formation is particularly susceptible to landsliding, because it consists of laminated beds of aragonite and marl. In places these have been deeply dissected to leave steep, unstable slopes. Relatively minor earthquakes are capable of causing failures in these slopes, as demonstrated by the Jordan valley earthquake of Sep 2, 1973. This triggered three landslides despite the fact that the magnitude of the event was only 4.5.

In the Levantine countries, coastal landsliding has occasionally been triggered by large earthquakes. For example, as a result of an earthquake in Syria in 859 AD "many bridges and villages were destroyed, and a mountain covered with 90 villages fell into the sea carrying with it 1,500 houses" (as cited in Ambraseys, 1961; p.23).

Landslides are also of relatively common occurrence in the mountains along the western margin of the Arabian peninsula. Ambraseys and Melville (1983) have listed landsliding that occurred in the Yemen Arab Republic in AD 857, 1255, 1400 and 1583. The 1941 earthquake near to Jizan in Saudi Arabia triggered landslides that blocked several roads. Earthquakes have also caused landsliding in the mountains of the Sinai peninsula (e.g. May 1, 1312 AD).

Whereas landslides and rockfalls are associated with steep gradients, LIQUEFACTION is normally restricted to flat alluvial areas where the ground water is close to the surface. As such, it is a hazard that is associated not so much with mountains, as with river floodplains and the intra-montaine basins that lie between mountain peaks.

The catalogue shows that liquefaction has been associated with some of the large earthquakes that have affected the marshy alluvial plains of Mesopotamia (see Figure 5.4). The subsoil of the plains is for the most part unconsolidated and water-saturated. When violently shaken by an earthquake, sediments of this type can collapse due to a sudden loss of cohesion. Heavy objects standing upon the sediments are caused to sink into the ground. For example, in 902 AD there was "an earthquake at Baghdad and Basra where many places sank into the ground" (as cited in Alsinawi and Ghalib, 1975; p.542). It is of concern to note that Basra is now the site of one of the largest oil terminals in the Middle East. In 1138 AD the town of "Ganzah was badly shaken and within its dependencies 230,000 persons perished. The town itself sunk and the place it occupied was covered with black water" (as cited in Ambraseys, 1961; p.25).

The coastal plains of the Levant have high water tables, and have consequently experienced liquefaction triggered by large offshore earthquakes. In the earthquakes of 140 BC and 1261 AD, the coast around Tyre (Lebanon) was badly affected by ground failure of this type.

The eastern Mediterranean seems to have been particularly prone to TSUNAMIS (seismic sea waves), generated by large offshore earthquakes or by submarine slumping. Ambraseys (1962) has shown that the intensity of these usually varies from "light" to "strong". Waves of higher intensities are very rare and strongly local. Figure 5.4 shows that the waves have affected the coasts of Syria, Lebanon, Israel and Egypt. Low-lying areas have been particularly susceptible to inundation. Major coastal cities such as Alexandria, Jaffa (Yafo), Akko, Haifa, Tyre, Sidon, Beirut and Tripoli have all been inundated on numerous occasions, whilst tsunamis in 23 BC and 1303 AD are reported to have flooded the entire Nile delta region. It is interesting to note that there is only one record of a tsunami in the Red Sea (i.e. that of July 23, 1884 AD).

The data in the historical catalogue would seem to suggest that tsunamis in the eastern Mediterranean have also occasionally been triggered by onshore earthquakes. For example, large earthquakes in northern Israel on Oct 30, 1759 and Jan 1, 1857 AD (both with epicentres close to Tzfat) were accompanied by tsunamis along the Levant coastline. Similarly, an earthquake in the Orontes valley of Syria on Aug 13, 1822 AD generated a tsunami that affected the Lebanese, Syrian and Turkish coasts. Such reports at first seem anomalous, but the fact that they are of relatively common occurrence makes this unlikely. A possible explanation for the tsunamis, therefore, is that they were triggered by submarine slumping caused by vibrations emanating from the onshore earthquakes. It would therefore seem that large onshore earthquakes in the Levant region pose an additional threat to low-lying coastal areas in the eastern Mediterranean.

SEICHES have frequently been associated with large earthquakes along the Dead Sea fault. These have affected the shorelines of the Dead Sea and Lake Tiberias. For example, earthquakes in BC 759 and AD 746, 1759 and 1837 (amongst others).

Figure 5.4 shows that there is considerable evidence for historical VOLCANIC ACTIVITY in western Arabia. This activity is related to the opening of the Red Sea (see Section 4.4.1), and has probably been associated with historical seismicity in the area (see Section 5.5.2.2). The catalogue contains no definite records of volcanic eruptions in Arabia prior to 640 AD. However, Stothers and Rampino (1983) suggest that a number of Biblical passages could have been inspired by Arabian eruptions prior to 700 BC.

Neumann van Padang (1963) provides evidence of volcanic lava flows that have occurred in western Saudi Arabia during historic times. For example, in the summer of 1256 AD, an Arabian volcano erupted producing a lava flow that was 19km long and 6km wide. The flow stopped just short of the city of Medina. Recent dating of volcanic flows along the Red Sea coastline suggests that many are much younger than was formerly believed, and may have occurred during historic times (Merghelani and Gallanthine, 1980).

Several Arabian volcanoes have shown signs of activity this century. In addition, there are a number of volcanoes in the Mediterranean that have been active during the past 200 years (Munich Re., 1984). There are numerous volcanic cones situated along the eastern margin of the Dead Sea transform fault (e.g. in the Golan Heights), though these are not thought to have been active for several thousand years. Nevertheless, the potential for volcanic activity obviously exists.

5.7.2 Earthquake-related hazards in the Middle East (Western part)

All the dates given in this section refer to earthquakes that occurred after Christ (AD).

Some of the best descriptions of ground FAULTING in North Africa refer to earthquakes that occurred in the Atlas mountains of Algeria and Morocco. For example, faulting accompanied the earthquakes of Jan 2, 1867 and Jan 15, 1891 in Algeria, and Nov 19, 1755 in Morocco.

It is highly likely that surface faulting is of more common occurrence in the Atlas than the historical data show. Once again, the records are probably poor simply because faulting has attracted less attention from chroniclers, than the damage inflicted by earthquakes upon centres of population. It is certainly the case that many 20th century earthquakes in the region have been accompanied by surface faulting. For example, the El Asnam earthquake produced surface faulting on a thrust fault 30-40km long, with an average displacement of about 3 metres (Yielding et al., 1981).

Ground failure of one sort or another has frequently accompanied earthquakes in North Africa, and served to increase the severity of earthquake impact upon certain areas (see Figure 5.10). The historical records show that ground failures have been triggered by low magnitude earthquakes as well as by large events, and that a variety of types of failure have been observed:

ROCKFALLS - These have often been triggered by earthquakes in the Atlas mountains, due to the fact that many of the slopes in this region are steep and unstable. For example, rockfalls were triggered by the Algerian earthquakes of Dec 3, 1885 and Jan 15, 1891. Coastal rockfalls in Morocco and Algeria have occasionally accompanied large offshore earthquakes. For example, the Lisbon earthquake of Nov 1, 1755 triggered rockfalls along the Moroccan coast.

LANDSLIDES - Numerous historical earthquakes have caused quite large tracts of land to slump or slide. For instance, the Algerian earthquake of Feb 3, 1716 caused a large landslide (4km long) close to Alger.

LIQUEFACTION AND SUBSIDENCE - During the Algerian earthquake of Aug 21, 1856, liquefaction occurred across the plain of l'Oued Merka. As a result of this, "large fissures formed in the soil from which shot out a considerable quantity of water to a height of several metres, carrying with it in some places large amounts of sand ... and in others mud" (as cited in Vogt, 1984; p.46 - translated from French). In the Tunisian earthquake of June 2, 854, "slumping and settling of the ground was observed in the valleys" (as cited in Ambraseys, 1962b; p.241).

TABLE 5.3

Some Ground Failures Associated with Twentieth Century Earthquakes in Northern Algeria

ROCKFALLS

YEAR	REGION OF EARTHQUAKE	ASSOCIATED GROUND FAILURE
1922	Ténès	Enormous blocks tumbled down from the sandstone ridge overlooking Kalloul
1943	Bibans	A block slide occurred on Djebel Mansourah
1948	Ksours	Rockslides triggered at Ain-Ourka
1949	Kerrata	Numerous rockslides triggered in the gorges of Chabet-El Akra, which partly blocked the Route Nationale
1974	Kerrata	Rockfall in the gorges of Kerrata
1979	Kerrata	Numerous rockfalls

LANDSLIDES

1934	Attafs	Landslides triggered in the region of Attafs
1980	El Asnam	Ground cracking, faulting and landslides in the Cheliff valley

Main sources of data: Ambraseys (1981); Roussel (1973); Vogt (1984); Yielding *et al.* (1981)

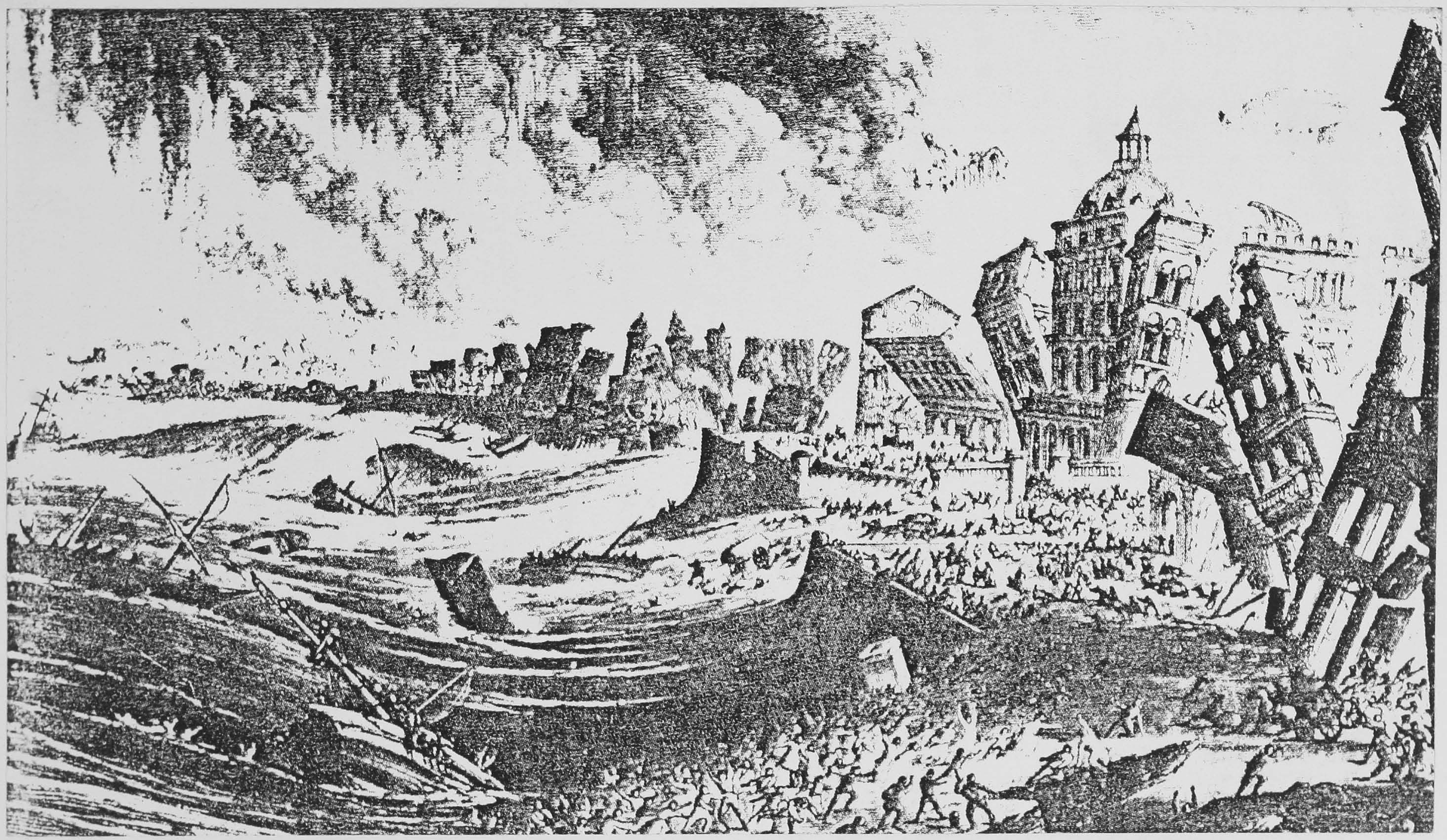
Liquefaction has been triggered in the coastal plains of North Africa by large offshore earthquakes. These plains are very susceptible to this type of ground failure because water tables are frequently high. For example, in the Algerian earthquake of Oct 9, 1790, liquefaction occurred in the low-lying areas of Oran.

Table 5.3 lists some ground failures that have been associated with 20th century earthquakes in the Atlas mountains of Algeria. It can be seen that the slopes of the Kerrata region have been particularly susceptible to earthquake-induced landsliding. In 1949 an earthquake of intensity VII caused numerous gravity movements in the region. These have since been reactivated by more recent earthquakes, and continue to be active today (Gabert, 1984).

The 1980 earthquake at El Asnam was associated with extensive ground deformations. Following the earthquake, land adjacent to part of the Cheliff river flooded to create a small lake. According to Ambraseys (1981) this suggests that this section of the valley floor had sunk by 1.5-2.0 metres. The earthquake also triggered numerous minor landslides (King and Vita-Finzi, 1981).

TSUNAMIS (Seismic sea waves) - Compared to the eastern Mediterranean, tsunamis have been of rare occurrence in the western Mediterranean. The catalogue shows that the part of the western Mediterranean that is most exposed to them is the coast of Algeria. This is because large magnitude earthquakes occasionally occur just off this section of coastline, generating quite large tsunamis in the process. For example, an earthquake that occurred several kilometres north of Jijel on Aug 21, 1856 (see Figure 5.10) produced

Figure 5.11 An old engraving of the destruction that accompanied the Lisbon earthquake of November 1, 1755



Scribner, Walford and Co., as reproduced in Holmes (1978, p.573) a tsunami that was up to 2.3 metres high along parts of the coast of Algeria.

In contrast to the western Mediterranean, the historical catalogue shows that tsunamis have occurred relatively frequently along the Atlantic coast of Morocco. This has been affected by seismic sea waves on more occasions than any other section of coastline in North Africa. The waves typically occur in association with large magnitude earthquakes along the Azores-Gibraltar ridge. For example, the Lisbon earthquake produced a very large tsunami that was responsible for much of the destruction experienced in coastal areas of Portugal and Spain (see Figure 5.11). The waves were between 15 and 40 feet high along the southern Iberian peninsula. They entered the English Channel and the North Sea, and were even noticeable in the West Indies.

Occasionally, tsunamis generated in the Atlantic have also affected the Mediterranean coastlines of Morocco and Algeria. For example, those associated with the earthquakes of March 31, 1761 and May 6, 1773. However, for the same Atlantic tsunamigenic event, the waves experienced in the Mediterranean tend to be smaller than those on the Atlantic coast. This is illustrated by the fact that the seismic sea waves produced by the 1773 earthquake were 30 feet high at Tanger, but only 6 feet high at Alger.

Figure 5.10 shows that there are no historical records of tsunamis along the coast of Tunisia. However, it is possible that the country could be affected by seismic sea waves generated as a result of large earthquakes in the eastern Mediterranean basin. The catalogue shows that Libya was affected by one such tsunami after a magnitude (ML) 7.7 earthquake near to Knossos (Crete) on July 21, 365.

VOLCANIC ERUPTION - There is no evidence of historical volcanic activity in North Africa. However, the catalogue shows that some of the historical earthquakes reported from the Canary Islands and the Azores have probably been of volcanic origin. For example, those of 1755 (Azores) and March 20, 1810 (Canary Islands). According to the Munich Re. (1984), the majority of the volcanoes that make up these islands have been active at some time or another since 1800 AD.

5.8 CONCLUSIONS

Only a brief account of the major conclusions to be drawn from the chapter will be presented here. A more comprehensive summary of conclusions will be presented in the next chapter.

This chapter has presented a detailed account of historical earthquake activity in the Middle East. The analysis has involved the compilation of a catalogue which summarises the available historical earthquake data for the region. The catalogue has been subdivided into two parts. Part I (Appendix A) covers the eastern part of the region, and Part II (Appendix B) the western part.

Part I of the historical catalogue extends back over a much longer time period than does Part II. Early earthquake records are quite comprehensive for the eastern part of the region due to the wealth of data that have been derived from Biblical, Greek and Roman sources. In contrast, the western part of the region has very good records for the more recent historical past. This is as a direct result of European interest and influence in North Africa during the 18th and 19th centuries.

Analysis of the distribution of historical seismicity in the Middle East shows that it has been greatest along (and adjacent to) the major tectonic units of the region (as described in Chapter 4). In the eastern part of the region, high rates of historical activity have been observed in the countries of the LEVANT. This is due to the combined effect of onshore and offshore tectonic zones. The highest incidence of earthquakes has been in Syria.

EGYPT and IRAQ have also experienced considerable historical seismicity. In the case of Iraq, this has mainly been the result of earthquakes in the Zagros fold belt. In Egypt, most large earthquakes that have affected the country have originated offshore, either in the eastern Mediterranean basin or northern Red Sea.

Lower rates of earthquake activity have been observed in the countries of the ARABIAN PENINSULA. The incidence of earthquakes has been greatest along the western margin of the peninsula, adjacent to the Red Sea and Gulf of Aden.

Within the aforementioned countries, the historical earthquake catalogue has served to highlight several areas that have been very susceptible to earthquake damage in the past. These include:

- The Nile delta;
- The Mesopotamian plain;

- The coastal fringes of the eastern Mediterranean.

These areas in themselves are not particularly seismically active. However, the presence of thick sequences of unconsolidated sediments makes them very sensitive to earthquake ground motions (particularly those generated by distant earthquakes). In many ways, this situation is analogous to that observed in the Valley of Mexico and the Balsas river delta during the 1985 Mexican earthquake (see Sections 2.13 and 2.13.1).

In the western part of the region, the highest rates of historical earthquake activity have been observed in ALGERIA. This is because the Atlas fold belt seems to have been more active in its central section than in either Morocco or Tunisia. Much of the historical earthquake damage in MOROCCO has in fact been caused by offshore earthquakes. The catalogue shows that LIBYA has been less seismically active than either Algeria or Morocco. Most of the damaging earthquakes that have affected the country have been of submarine origin.

In all the countries of North Africa, the incidence of earthquakes has been greatest in northern and littoral regions, and decreases in a southerly direction.

A variety of natural hazards have been associated with earthquakes in the Middle East. These include volcanoes, faulting, ground failures (landslides, rockfalls, liquefaction), tsunamis and seiches. Very often, hazards of this type have served to increase the severity of earthquake impact upon human settlements.

The catalogue shows that VOLCANIC ACTIVITY has largely been confined to the western Arabian peninsula, eastern Mediterranean basin and Canary Islands. FAULTING has been observed along the Dead Sea rift and in the Atlas mountains of North Africa. LIQUEFACTION has frequently accompanied large earthquakes that have affected low-lying areas of water-saturated sediment (e.g. the Mesopotamian plain and coastal margins). Away from alluvial areas, the severity of earthquake impact upon mountainous terrain has often been increased by ROCKFALLS and LANDSLIDES (e.g. in the Atlas mountains). Finally, many low-lying coastal areas have proven susceptible to TSUNAMI inundation. The catalogue shows that the tsunamis have been generated by both onshore and offshore earthquakes. The incidence of them has been much greater in the eastern Mediterranean basin than in the western basin. Large tsunamis have also been recorded along the Atlantic coastline of Morocco. On a smaller scale, seismic SEICHES have affected the shores of Lake Tiberias and the Dead Sea in Jordan and Israel.

5.8.1 The value of the historical data

The historical earthquake catalogue serves to extend the time period over which earthquake data for the Middle East are available. In doing so, it permits a more meaningful sample of the long term seismicity of the region to be taken. However, the historical data have to their disadvantage the fact that they are largely descriptive, and are concerned mainly with the EFFECTS of earthquakes. They provide little reliable information concerning the nature and point of origin of the seismic events themselves. Such information is best obtained by using instrumentally recorded 20th century earthquake data.

To be totally comprehensive, an assessment of earthquake hazard in a region must therefore draw upon data provided by both 20th century (instrumental) investigations and historical (macroseismic) studies. The purpose of the next chapter is to present such an analysis for the Middle East. 20th century data (Chapter 4) and historical data (Chapter 5) are analysed together, in an attempt to produce a comprehensive assessment of the distribution of earthquake hazard in the region.

CHAPTER 6. THE DISTRIBUTION OF EARTHQUAKE HAZARD IN THE MIDDLE EAST

6.1 INTRODUCTION

In Chapter 4 a detailed analysis of the tectonic setting and 20th century seismicity of the Middle East was presented. Chapter 5 contained an in-depth analysis of the historical seismicity of the region. The purpose of this chapter is to take the data from these previous two chapters, and use them to present a comprehensive account of the distribution of earthquake hazard in the Middle East.

The chapter begins by comparing the impressions of earthquake hazard distribution given by historical and recent (20th century) earthquake data for the Middle East. This permits a comprehensive evaluation of earthquake hazard across the entire region, based upon a record of earthquake activity that (for parts of the region) extends back over 4,000 years.

Having produced an assessment of the distribution of earthquake hazard in the Middle East, an attempt is then made to relate this to current patterns of population density and economic development in the region. The purpose of this is to summarise the potential for earthquake-induced losses in the Middle East (both in human and economic terms).

The chapter concludes with an analysis of fluctuations in the seismicity of different Middle Eastern countries through time. Possible reasons for these fluctuations are discussed in detail, and an attempt is made to use them to explain the present-day distribution of earthquake activity in the region. The implications of temporal variations in seismicity for earthquake hazard assessments are discussed.

6.2 COMPARISON OF HISTORICAL AND RECENT EARTHQUAKE ACTIVITY IN THE MIDDLE EAST

Ambraseys (1971) has shown that in certain parts of the Middle East, the distribution of 20th century seismicity need not necessarily reflect the distribution of historical earthquake activity. The purpose of this section, therefore, is to compare the impressions of earthquake hazard given by recent (Chapter 4) and historical (Chapter 5) earthquake data for the Middle East. By combining observations drawn from the two sets of data, it is hoped to produce a comprehensive assessment of the distribution of earthquake hazard in the region.

6.2.1 Eastern part of the region

Figure 4.1 shows the distribution of significant 20th century earthquake activity in the eastern part of the region. Figure 5.4 summarises the historical data that are available for the same area. If the two diagrams are compared, it can be seen that they give a similar impression of the distribution of earthquake hazard. There are, however, some important differences between the two. Not all of these differences can be attributed to the fact that the historical data are mainly concerned with the effects of earthquakes, whereas the recent data describe the earthquake events themselves (i.e.

location, depth and magnitude).

20th century earthquake data give the misleading impression that Egypt is unaffected by large earthquakes. Historically, earthquakes of this type have occurred within the delta region, albeit at long time intervals. In addition, the historical record shows that north and north-eastern Egypt are vulnerable to damage caused by large earthquakes in the Mediterranean and Red Seas. Both these tectonic zones have experienced considerable seismic activity during the present century. The northern Red Sea region, at the entrance to the Gulf of Suez, has been particularly active in recent years. A large earthquake of Richter magnitude 7.0 occurred close to the Shadwan Islands in 1969, causing some damage in northern Egypt. Micro-earthquake data (concerning seismic events with Richter magnitude less than 4.0) obtained by Dagget et al. (1980), indicate that the southern end of the Gulf of Suez is extremely active. In addition, Morgan et al. (1981) have recorded micro-earthquake activity in the north-eastern part of the Eastern Desert of Egypt, 25km inland from the Red Sea coast. They report that Bedouins have known of earthquake activity in the region for several generations.

20th century seismic data support the impression gained from the historical record that most earthquake activity in Israel, Jordan and Lebanon is concentrated along the rift valley. Figure 4.1 and Table 3.6 show that several large and damaging earthquakes have occurred along or adjacent to the rift this century. These include the 1927 event at Nablus (West Bank), and that of 1956 at Chouf (Lebanon). Wu et al. (1973) have shown that there is considerable micro-earthquake activity along the Jordan rift.

The Arava section of the rift (south of the Dead Sea) has seen very little 20th century earthquake activity. This is in agreement with the distribution of historical earthquake activity in the region. The 20th century data suggest that the paucity of historical earthquake reports for the southern section of the rift, is due to a real lack of seismic activity. It has not been caused merely by poor observation. Ben-Menahem (1981) has suggested that the Arava fault is a region of high aseismic slip. He attributes this to the fact that in Arava, the Earth's crust is thinner and less rigid than along other parts of the rift valley. Large earthquakes will therefore only occur on very rare occasions. For example, the earthquake in 1067 AD that destroyed Eilat in southern Israel. Further north along the rift, aseismicity tends to disappear altogether, and slip is purely seismic (i.e. in Syria).

In accordance with the pattern of historical earthquake activity, there has been no significant 20th century seismicity along the southern coastal plain of Israel. Similarly, the Negev and inland Sinai have been quiescent.

20th century data emphasise the threat posed to the coastal cities of the Levant by offshore earthquakes in the eastern Mediterranean basin. Figures 4.1 and 4.3 show that a large number of submarine earthquakes occur between the Lebanese-Syrian coast and Cyprus. The threat posed by these offshore events should not be underestimated. The historical record shows that large earthquakes of this type have repeatedly caused damage throughout the entire eastern Mediterranean. In this context, intermediate-depth earthquakes associated with subduction along the Cyprian and Cretan arcs (see

Figure 4.2), are likely to have the potential to shake the largest areas.

The Syrian fault system has experienced only minor seismic activity this century, and has not generated any major earthquakes. This noticeable lack of instrumental data contrasts quite vividly with the impression given by the historical record for the region. It must therefore be concluded that the Syrian fault system is at present in a phase of relative quiescence. The historical data would seem to suggest that this phase will not continue indefinitely. Temporal fluctuations in Syrian seismicity will be discussed in greater detail in Section 6.4.

The historical seismicity of Iraq correlates well with the seismicity of the country during the present century. The distribution of 20th century epicentres follows the trend of the Zagros tectonic zone, with the result that the north and north-eastern parts of the country have experienced the greatest seismic activity. Al-Jassar (1972) has calculated that between 1900 and 1971, 86.4% of the earthquakes recorded in Iraq occurred east of the River Tigris. Alsinawi and Banno (1976) have demonstrated that micro-seismicity also shows an increase from the south-west to the north-eastern parts of the country. The strong diminution of earthquake activity in the western and south-western parts of Iraq indicates a tectonically stable region.

One aspect of earthquake hazard in Iraq that cannot be fully appreciated by analysing 20th century seismic data alone, is the sensitivity of the Mesopotamian plain to earthquakes in the Zagros. As mentioned in Section 5.5.2.2, the historical data show that despite the fact that few earthquakes occur in the plains region, some of the heaviest earthquake damage experienced in Iraq has been upon the marshy alluvial sediments of Mesopotamia.

In addition to the northern part of the Red Sea rift (referred to above), the mid to southern sections have also experienced considerable earthquake activity this century. Most of the earthquakes have been along the axial trough of the rift. However, there is little historical evidence of earthquakes of this type having caused damage in the coastal margins of the Arabian peninsula. A possible reason for this has been provided by Molnar and Oliver (1969) and Barazangi (1981). They have shown that the shock waves produced by earthquakes in the axial trough, are rapidly attenuated during their propagation through the partially melted uppermost mantle material that exists along the rift. Added to this is the fact that Red Sea earthquakes are predominantly of shallow focal depth (<100km), and are therefore unlikely to affect large areas.

Few earthquakes have been instrumentally recorded along the coastal plains and western margin of the Arabian plate during the present century. This gives the misleading impression that the area is largely aseismic. However, the historical record reveals evidence of significant earthquake activity in the north-western and south-western parts of the Arabian peninsula. An indication that this activity continues today was provided by the "surprise" earthquake that badly affected the Dhamar district of the Yemen Arab

Republic in December, 1982 (see Table 3.6). Similarly, Gutenberg and Richter (1965) report an earthquake of magnitude 6.25 that occurred close to Jizan (Saudi Arabia) in January, 1941. Rothe (1969) lists an earthquake of magnitude 5.5 that occurred near to the Saudi-Yemeni border in October, 1965. Recently, several micro-earthquake investigations have monitored considerable micro-seismicity along the coast of western Saudi Arabia (e.g. Merghelani and Gallanthine, 1980; Merghelani et al., 1981). The presence of these micro-earthquakes indicates that there are active faults in the region.

All this evidence suggests that the impression given by the historical data is a real one, and that earthquake hazard along the western margin of the Arabian peninsula should not be underestimated. In contrast, the absence of both recent and historical earthquake activity from the central and eastern parts of the peninsula would seem to indicate that they are largely aseismic. The catalogue shows that the littoral regions (in the south and east) may occasionally be subject to earthquakes originating in south-western Iran, The Gulf and the Arabian Sea.

6.2.2 Western part of the region

Figures 4.4 and 4.5 show the distribution of significant 20th century earthquake activity in the western part of the region. Figure 5.10 summarises the historical data that are available. Once again, the two sets of diagrams give very similar impressions concerning the distribution of earthquake hazard in this part of the Middle East.

Above all else, the 20th century data emphasise the importance of the Alpide tectonic belt in controlling the overall distribution of seismic activity in this part of the region. On land, there are clearly defined northern and southern limits to the seismicity. Similar limits exist to the distribution of historical earthquake activity in the region.

In North Africa the southern limit of seismic activity is marked by the South Atlas fault, to the south of which lies the seismically stable Sahara block (see Figure 4.6). In Spain, the limit of intense seismicity is marked by the Guadalquivir fault, to the north of which lies the stable Spanish plateau.

20th century data confirm the impression gained from the historical catalogue, that the Azores-Gibraltar ridge is associated with the sporadic occurrence of large magnitude earthquakes capable of causing damage in the southern Iberian peninsula and northern Morocco. The earthquakes of 1941 and 1969 that occurred along the ridge were both shallow-focus events with magnitudes greater than 8.0. Figure 4.4 shows that the epicentre of the 1969 event was over 450km from the Moroccan coastline. Despite this, the earthquake caused damage in Morocco (Adams and Barazangi, 1984).

Figure 4.4 shows that east of the Straits of Gibraltar, earthquake epicentres cease to be concentrated along the axis of a single ridge. Instead, they are spread over a wide area covering the Alboran Sea, southern Spain and northern Morocco. 20th century data support the impression gained from the historical catalogue, that the percentage of shocks with large magnitudes (i.e. greater than

7.0) is considerably smaller to the east of the Straits than it is to the west. The majority of recent seismicity in the Alboran Sea has been of moderate magnitude (i.e. 5.0 to 6.0). The only large earthquake to occur east of Gibraltar during the present century was that of March 29, 1954, in the Granada region of southern Spain. This event had a magnitude of 7.0, but was very different from the earthquakes of the Azores-Gibraltar ridge in that it had a focal depth of 650km.

Historical and instrumental earthquake data both show that most of the onshore earthquake activity in Morocco, Algeria and Tunisia is confined to the vicinity of the Atlas mountains. In accordance with historical observations, 20th century seismicity has not been uniform along the entire Atlas fold belt. Figures 5.9 (historical data) and 4.4 (instrumental data) show that the activity experienced in the central parts of the Atlas (Algeria), is considerably greater than that observed in either Morocco or Tunisia. A possible reason for this was given in Section 5.6.2.1.

Moderate magnitude earthquakes have occurred along the Atlas and Rif belts of Morocco during the present century. According to Adams and Barazangi (1984), about 30 Moroccan events per year have magnitudes of between 4.0 and 5.0. The largest onshore event of recent years was that of February 29, 1960, at Agadir. Although of only moderate magnitude (5.9), the earthquake was strongly felt and caused intensive damage because of its shallow focal depth. This is in accordance with the descriptions of historical earthquake damage in the Moroccan Atlas. Many earthquakes caused high intensity damage over relatively small areas.

Figure 4.4 shows a marked absence of any significant seismic activity in the south-western Atlas region of Morocco, close to Marrakech. In view of the fact that this region has historically experienced considerable earthquake damage, it seems reasonable to assume that it may well be overdue for an earthquake of moderate magnitude.

The distribution of 20th century seismic activity in Algeria closely matches the distribution of historical earthquake activity in the country. The highest incidence of earthquakes occurs in the extreme north of the country along the Tell Atlas, with greatly reduced rates of seismicity in the Saharan Atlas to the south. Within the Tell Atlas, the largest event to have occurred since 1900 was that at El Asnam on October 10, 1980 (magnitude of 7.2). This earthquake was the second major event to strike the town this century - Table 3.6 shows that on September 9, 1954, a magnitude 6.7 earthquake almost totally destroyed El Asnam (ex Orleansville). It is interesting to note that prior to the earthquake of 1980, it had not been thought likely that earthquakes with magnitudes greater than 7.0 would occur in Algeria (Ambraseys, 1981).

Figure 4.4 shows that compared to the onshore region, the offshore region of Algeria is not particularly seismically active. Once again this is in agreement with the conclusions drawn from the historical data.

As was the case with the historical seismicity of Tunisia, 20th century earthquake activity has been restricted to the central and northern parts of the country. Tunisia has not experienced any particularly large earthquakes this century. The largest event in recent years was an earthquake of magnitude 4.9 that affected the north of the country in 1979 (Adams and Barazangi, 1984). Rothe (1969) assigned a magnitude of 5.9 to a Tunisian earthquake that occurred close to the Algerian border in 1957. This earthquake caused 13 deaths and injured 102 people.

The fact that Tunisia has not experienced any large magnitude earthquakes this century, should not be taken to minimise the maximum likely magnitude of earthquake that can be expected in the country. The historical data clearly show that high magnitude earthquakes do occur in Tunisia, albeit at very long time intervals.

Figure 4.4 shows that the immediate offshore region of Tunisia is not particularly seismically active, and the historical data support this. The tectonic zones around Sicily (to the east of Tunisia) have been associated with considerable seismic activity this century. However, the historical data would seem to suggest that Sicilian earthquakes seldom cause damage on the Tunisian mainland.

20th century seismicity reinforces the impression gained from historical data that earthquake hazard in Libya is greatest in the northern and littoral parts of the country. Figure 4.5 shows that offshore tectonic zones to the north-east of Libya have been particularly active this century. The presence of these tectonic zones helps to explain the relatively high incidence of historical earthquake damage observed in Cyrenaica (the Jabal al Akhdar region). Several towns in the region have been affected by medium magnitude earthquakes this century. For instance, Al Marj (ex Barce) was heavily damaged by an earthquake on February 21, 1963. This earthquake had a magnitude of 5.3, and was followed by five small aftershocks. Susah was affected by offshore earthquakes in 1918 and 1943 (Kebeasy, 1981).

Offshore earthquakes have affected other parts of Libya during the 20th century. For instance, on December 19, 1976, Tripoli and its environs were shaken by an offshore event with a magnitude of 4.8. The historical data suggest that large earthquakes in the eastern Mediterranean basin occasionally affect Libya. Proof of this was provided by an intermediate-depth earthquake that occurred near to Rhodes on June 26, 1926. The earthquake had a magnitude of 8.0, and was felt in Turkey, Israel, Egypt, Libya and Italy.

The 20th century data provide evidence of areas of onshore tectonic activity in Libya, for which there are no historical earthquake data. For example, the largest earthquake observed in Libya this century occurred east of the Hun graben (see Figure 4.6) on April 19, 1935. Although this earthquake had an estimated magnitude of 7.1, no damage was reported because the epicentre was in a sparsely populated desert area (Kebeasy, 1981). Low population densities may account for the lack of historical data from this part of Libya. Another earthquake (magnitude 5.3 - 5.9) occurred in the vicinity of the Hun graben on January 23, 1939. This was followed by a similar event on March 4, 1941 (Kebeasy, 1981).

Instrumental data would seem to suggest that the whole of southern Libya is entirely aseismic. Figure 4.5 shows that there has been no significant earthquake activity in this part of the country during the 20th century. However, the historical data provide evidence of some earthquake damage in the Fezzan district of south-west Libya (see Figure 5.10). In view of this, the threat posed by earthquakes to the southern part of the country should not be completely overlooked.

6.3 EARTHQUAKE LOSS POTENTIAL IN THE MIDDLE EAST

In the previous section, historical and instrumental earthquake data for the Middle East were used to present a detailed description of the distribution of earthquake hazard. The purpose of this section is to summarise the potential for earthquake-induced losses in the region.

Earthquake hazard in the Middle East is greatest along (and adjacent to) the major tectonic zones. Unfortunately, many of the major urban centres of the region and much of the industrial development are concentrated within these hazardous areas (see Figures 3.5 and 3.6). In Section 3.3.1.2 it was demonstrated that the densest concentrations of Middle Eastern population are found in coastal areas or along the major river valleys. In many parts of the region, these particular areas are the ones that are most exposed to earthquake hazard. It is perhaps ironic that the lowest population densities in the region occur in areas of negligible earthquake hazard. For example, in the centre of the Arabian peninsula and in the southern parts of the North African countries.

6.3.1 Eastern part of the region

The potential for large earthquake losses is particularly great in the coastal belt of the eastern Mediterranean. The high-magnitude (intermediate-depth) earthquakes generated in the eastern Mediterranean basin, are amongst the largest experienced in the Middle East (e.g. those along the Cyprian and Cretan arcs - see Figures 4.2 and 4.3). Some are undoubtedly capable of affecting the entire eastern Mediterranean coastline.

Figure 3.3 shows that the Levant coastal region is one of the most densely populated parts of the Middle East. Many of the major Levantine cities are very vulnerable to earthquake ground motions, because they are situated upon unconsolidated coastal sediments. A large offshore earthquake could, therefore, result in great loss accumulations in the coastal cities. Such an earthquake would probably be accompanied by a tsunami, and this would only serve to increase the losses experienced in low-lying coastal areas (e.g. the Nile delta).

The threat posed by submarine earthquake events to the coastal cities of the Levant is now greater than it has ever been. This is because of the large number of high-rise developments that have taken place in the region in recent years. Experience gained from the 1985 Mexican earthquake (Chapter 2), has shown that medium to high-rise structures are much more sensitive to distant earthquake events than low-rise ones. This is because they have longer natural periods of vibration, and are therefore more likely to be in tune with the low frequency shock waves associated with distant earthquake events (for full discussion see Sections 2.10.3 and 2.13.2). Due to their ability to "feel" earthquakes over greater distances, the high-rise coastal cities of today are undoubtedly more vulnerable to earthquake damage than the low-rise cities of the past. A distant large offshore earthquake 40 years ago (or 4 centuries ago) would have caused practically no damage in coastal cities such as Latakia, Beirut, Haifa, Tel Aviv-Yafo, Alexandria and Tripoli. The same earthquake today would result in untold damage and destruction to a large number of the tall structures in these cities.

High-rise construction has served to increase vulnerability to earthquake loss in many other parts of the Middle East. In Sections 5.5.2.2 and 5.8, it was shown that large earthquake losses have been experienced in the cities of the Nile delta and Mesopotamian plain (e.g. Cairo and Baghdad). The majority of earthquakes that affect these alluvial areas originate along distant tectonic zones (i.e. earthquakes in the Mediterranean and Red Seas affect the Nile delta, while those in the Zagros mountains affect Mesopotamia). Increased heights of construction in the two regions, can only serve to increase vulnerability to this type of earthquake.

The potential for earthquake induced losses varies quite considerably in the Arabian peninsula. Beyond doubt, the severity of earthquake hazard along the western margin of the peninsula has been underestimated in the past. Figure 3.6 shows that parts of the coastline of the Gulf of Suez and Red Sea are currently under intensive urban, industrial and touristic development. In view of this, the likelihood of large earthquake-induced losses in this part of the region is now greater than ever before.

The interior of the Arabian peninsula is largely aseismic. However, as already mentioned, population densities are extremely low in this part of the region. On a positive note, there would seem to be minimal earthquake hazard along the southern margins of The Gulf. This is fortunate in view of the phenomenal amounts of investment and development that have taken place in the Gulf States in recent years (see Figure 3.6). However, the threat posed by distant earthquakes to the Gulf region should not be completely overlooked (e.g. those in south-west Iran - see Figure 4.1).

6.3.2 Western part of the region

In all of the countries in the western part of the region, earthquake hazard is greatest in northern (and littoral areas), and decreases in a southerly direction. This is due to the combined influence of offshore and onshore tectonic zones. Figures 3.4 and 3.5 show that the areas of greatest earthquake hazard are also the ones that are most densely populated and industrialised. Conversely, the southern parts of Morocco, Algeria, Tunisia and Libya, are largely aseismic, but support very low population densities. There is consequently considerable potential for earthquake-induced losses in these countries.

In Algeria the seismicity of the Tell Atlas (in the far north of the country) is considerably greater than that of the Saharan Atlas to the south. This is of concern because the majority of major Algerian cities lie along, or adjacent to, the Tell Atlas. In Morocco, two zones are exposed to earthquake hazard; a coastal zone, affected by large offshore earthquakes, and an interior zone affected by the Atlas and Rif tectonic belts. Figure 3.5 shows that much of the urban and economic development that has taken place in Morocco has been in the Atlantic coastal zone. There is therefore considerable potential for large earthquake losses in this part of the country.

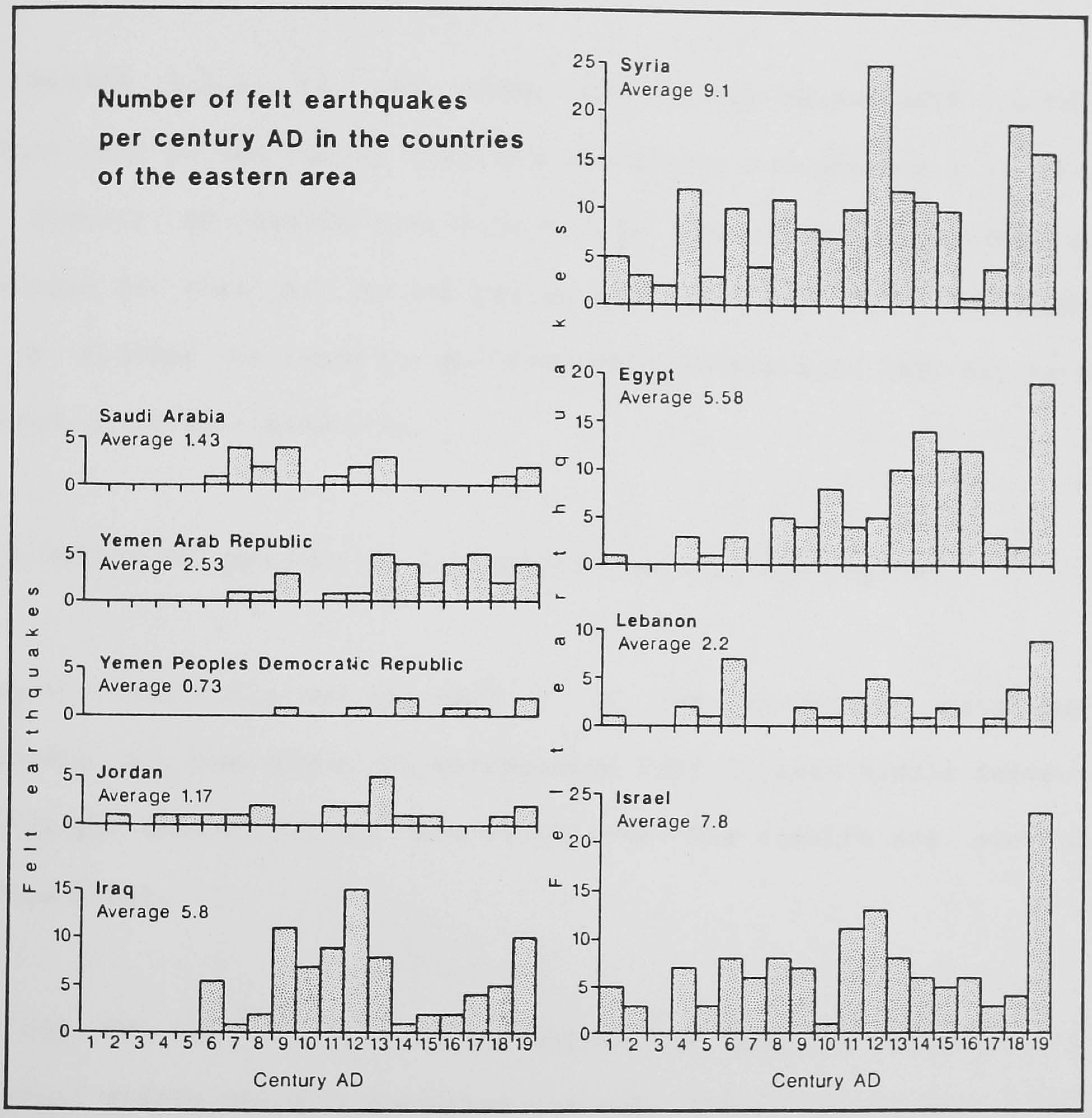
The seismicity of the western Mediterranean basin is much less than that of the eastern basin. The likelihood of large earthquake loss accumulations in the countries surrounding the western Mediterranean is therefore not as great. In contrast, offshore seismic events associated with the Azores-Gibraltar ridge (Atlantic Ocean) have considerable loss-inflicting potential. High magnitude earthquakes along this zone are capable of simultaneously affecting large parts of the southern Iberian peninsula and northern Morocco. Once again, vulnerability to this type of earthquake event has increased due to the large amounts of high-rise construction that have taken place in the coastal cities and resorts of the region.

6.4 TEMPORAL FLUCTUATIONS IN SEISMIC ACTIVITY IN THE MIDDLE EAST

To a large extent, much of the discussion in Chapters 4, 5 and 6 has been concerned with analysing the distribution of earthquake hazard in the Middle East. The study would therefore be incomplete without a discussion of temporal aspects of seismicity in the region.

Fluctuations in the historical seismicity of the western part of the study area were briefly mentioned in Section 5.6.2.1. It was shown that a marked increase in the seismic activity of the

Figure 6.1


Number of felt earthquakes per century AD in the countries of the eastern area
Syria
Average 9.1
Egypt
Average 5.58
Lebanon
Average 2.2
Israel
Average 7.8
Saudi Arabia
Average 1.43
Yemen Arab Republic
Average 2.53
Yemen Peoples Democratic Republic
Average 0.73
Jordan
Average 1.17
Iraq
Average 5.8
Felt earthquakes
Century AD
Century AD

Azores-Gibraltar ridge occurred during the 18th century. However, all in all, the data from the western part of the region are not well suited to temporal analysis, because of the poor quality of the historical record prior to the 18th century AD (see Figure 5.7).

In Section 5.5.1, it was shown that the earthquake data for the eastern part of the Middle East are relatively homogeneous from the 6th century AD onwards (see Figure 5.2). The historical earthquake catalogue for this part of the region has therefore been analysed, in an attempt to identify any temporal fluctuations that may have existed in seismic activity.

6.4.1 Method of analysis in the Eastern part of the region

Using the data contained in Part I of the earthquake catalogue (Appendix A), the number of earthquakes FELT in each Middle Eastern country per century AD has been calculated. The results are plotted in Figure 6.1.

The aim of the analysis is to compare the <u>relative</u> seismicity of different Middle Eastern countries through time. Consequently, no attempt has been made to assign earthquakes to particular tectonic zones. Earthquakes that affected more than one country have been included in the listings of all the countries in which they were felt. In this way, the pattern of relative activity between the affected countries remains the same, whilst changing in relation to the unaffected countries.

Figure 6.1 shows that the best earthquake frequency histograms are those of Egypt, the Levantine countries and Iraq. This is simply because of the large number of historical earthquake records that exist for each of these countries. Most of the histograms show a dramatic rise in the number of earthquakes felt during the 19th century. This is due to the improved means of communication and earthquake monitoring that developed throughout the the Middle East during the 1800's. Prior to this period, the majority of the earthquake frequency graphs show marked fluctuations through time.

In Egypt, for instance, there seems to have been an initial peak in earthquake activity during the 10th century AD. This was followed by a slight lull during the 11th and 12th centuries. A second peak occurred between the 13th and 16th centuries inclusive. This too was followed by a lull in the 17th and 18th centuries.

The frequency histogram for Israel is almost the complete opposite of that for Egypt. Following a marked quiescent period in the 10th century, there was an upsurge in the number of felt earthquakes during the 11th and 12th centuries, tailing off to a lull between the 14th and 18th centuries inclusive. Though less well defined, a similar pattern to this is observed for Jordan and Lebanon.

In Syria, temporal fluctuations in the number of felt earthquakes are remarkably similar to those observed in the other countries of the Levant. The record from the 3rd to the 8th centuries reveals a cyclical pattern, with active centuries followed by quiescent. Once again, the 10th century shows a relative lull in observed activity, followed by a very dramatic upsurge in the 12th century. The marked drop in the number of recorded earthquakes in the 16th century, is followed by another upsurge in the 18th century.

The time distribution of felt earthquakes in Iraq compares favourably to those of the Levantine countries, with a peak of activity during the 12th century. In Iraq, the marked lull in activity which succeeded this occurred in the 14th century, and was therefore slightly earlier than those observed in the Levant. From the 15th century onwards, there was a gradual rise in the number of earthquakes felt in the country.

The histograms for the Yemen Republics show less marked fluctuations through time. The best record belongs to the Yemen Arab Republic. To some extent it is similar to the Egyptian frequency histogram, in that it shows a drop in recorded earthquakes during the 11th and 12th centuries. There is increased activity from the 14th century onwards, with slight reductions in the 15th and 18th centuries.

The record for Saudi Arabia is poor, but the frequency histogram would seem to suggest sporadic earthquake activity.

6.4.2 Explaining the earthquake frequency histograms

There are three possible explanations for the apparent fluctuations in earthquake activity observed in different Middle Eastern countries:

a) It is possible that the peaks and troughs in the histograms are the result of fluctuations in the quality of the historical record through time;

b) The fluctuations may represent genuine periods of increased and decreased seismic activity. Fluctuations of this type are known to have occurred in other seismic regions of the world. For example, in China (York _et al_., 1976);

c) The fluctuations could be the result of a combination of factors (a) and (b).

6.4.2.1 Explaining the histograms in terms of the quality of the historical record

The history of the Middle East is an extremely complex one. The region has experienced a large amount of political instability, which has resulted in the cultural emergence and regression of different areas through time. This is likely to have had a considerable effect upon the quantity and quality of the documentation produced by chronographers and historians for different parts of the region at different times.

Figure 6.1 shows that prior to the 6th to 7th centuries AD, earthquake records are absent (or few in number) for many of the countries of the region. The most likely reason for this is that south-west Asia underwent marked economic decline following the break up of the Roman Empire in the 5th century AD. The region was plunged into a prolonged period of savage warfare between Byzantium and the Persian Sassanids (Beaumont _et al_., 1976). Overland trade routes between Europe and Asia were abandoned, depriving many ports and inland towns of their livelihood. Great cities became deserted, and many fell into ruins (e.g. Palmyra and Antioch).

Decline in the region was brought to a halt by the Islamic conquests that followed the death of Mohammed in 632 AD. The first three centuries of Islamic domination were a period of marked urban revival and prosperity throughout south-west Asia and North Africa. Islam originated in part of what is now Saudi Arabia. Figure 6.1 shows that the earliest earthquake records for countries of the Arabian peninsula, approximate to the start of the Islamic period. The same is true of Iraq. However, the frequency histograms for the countries of the Levant, and for Egypt, show no such correlation. This is probably because Islam had a less pronounced effect upon them, than upon parts of the western Arabian peninsula (where trade and external communication had never flourished before).

The resurgence of trade that followed the spread of Islam continued until the 11th century, when Islamic urban civilization reached its peak (Beaumont et al., 1976).

The earthquake maximum of the 11th and 12th centuries in the Levantine countries, coincides with the time of the Christian Crusades. The First Crusade set out in 1097 AD, with the objective of ejecting the Muslims from the Holy Places. By the early 12th century, the leaders of the Crusade had firmly established themselves in Palestine and Syria, and had succeeded in storming Jerusalem. Improved communication links with the west, meant that coastal ports such as Acre (Akko) and Sur (Tyre) grew rich on trade brought across the Mediterranean by Genoese, Pisan and Venetian merchants. There were even emigration programmes designed to populate the Holy Land with European settlers, who were enticed with promises of land, a house and release from serfdom (Billings, 1987).

Due to increased Western interest in the region, the documented history of the Levant might be expected to be better during the time of the Crusades than at any other period. This could provide an explanation for the peaks of earthquake activity observed in the Levantine countries during the 11th and 12th centuries. However, close examination of the historical evidence shows that this fact alone does not provide an entirely satisfactory explanation.

To begin with, Figure 6.1 shows that the increase in the number of earthquakes felt in Israel commenced in the 11th century, and not the 12th. As already mentioned, the First Crusade did not leave Europe until 1097 AD (following the proclamations of Pope Urban II in 1095 AD). The presence of Crusaders cannot therefore be used to explain the increased number of earthquakes recorded in Israel during the 11th century.

Similarly, the upsurge of activity in Syria, Israel and Lebanon terminated abruptly after the 12th century, despite the fact that Crusader influence was still present in the region. During the 13th century, the Crusaders ruled over the Levant from Acre (Akko). They were undoubtedly present in large numbers, as they managed to recapture Jerusalem from the Muslims in 1229 AD, and occupied it until 1244. It was not until 1291 that the Crusaders were finally driven out of the region by the Muslims (Billings, 1987).

During the 12th century, the influence of the Crusaders extended beyond the Levantine region. They occupied regions to the east of the River Jordan, astride the main caravan routes to the Red Sea. Several Crusader Barons established fortresses along the Gulf of

Aqaba, and exerted an influence over the Red Sea coast as far south as Medina (Billings, 1987). If improved documentation by the Crusaders were the sole reason for the upsurge in activity recorded in the Levant, it would be reasonable to expect a similar (12th century) peak in the frequency histogram for Saudi Arabia (i.e. in response to records of Saudi Arabian earthquakes made by the Crusaders). The fact that the Saudi Arabian histogram does not show such a peak, would seem to suggest that the surge in activity in the Levant was a real one, and that it did not extend south to Arabia.

All the above evidence suggests that the upsurge in the seismic activity of the countries of the Levant during the 11th and 12th centuries, cannot be explained simply in terms of improved documentation of earthquake events. It is possible that the earthquake maximum should be given less prominence than is due to it on a numerical basis only. However, there can be little doubt that this was the most active seismic period in the Levant region during historical times.

Syria, in particular, seems to have been subject to several earthquake-trains of prolonged duration during the 12th century. Poirier and Taher (1980) have presented a detailed chronology of one of these seismic episodes. It occurred between 1156 and 1159 in the Orontes valley of northern Syria, and involved a series of large earthquakes with many fore- and aftershocks. A number of the earthquakes also affected the countries to the south of Syria (e.g. Lebanon and Israel).

The reduced rate of seismic activity in the Levantine countries during the 13th to 17th centuries (inclusive) may not be entirely real. Amiran (1952) has suggested that it could be due, in part, to the incompleteness of records during this period of general cultural regression in the region. In Damascus, for example, cultural life entered a period of decline under Mamuluk and Ottoman rule between the 15th and 18th centuries. However, once again this does not seem to provide an entirely satisfactory explanation for the fall in recorded earthquake activity throughout the entire Levant region. Without more detailed information, it is difficult to prove whether or not the lull in activity is the sole result of bad documentation.

The peak of earthquake activity in Iraq during the 12th century can possibly be attributed to the work of two chroniclers who worked in Baghdad during this period. Ibn al Djawzi lived in the city between 1116 and 1201 AD, and Sibt Ibn al Djawzi between 1186 and 1257 AD (see Section 5.3). Opinion concerning the lull in activity between the 14th and 18th centuries is divided. Alsinawi and Ghalib (1975) have studied the time distribution of earthquakes that caused damage to two major cities in Iraq (i.e. Baghdad and Mosul). They have determined that between the 13th and 15th centuries, the number of earthquakes recorded at Baghdad dropped noticeably. A similar quiescent period was observed in Mosul between the 14th and 15th centuries. Alsinawi and Ghalib have suggested that because the quiescent periods observed in the two cities overlap, they represent phases of genuine seismic inactivity.

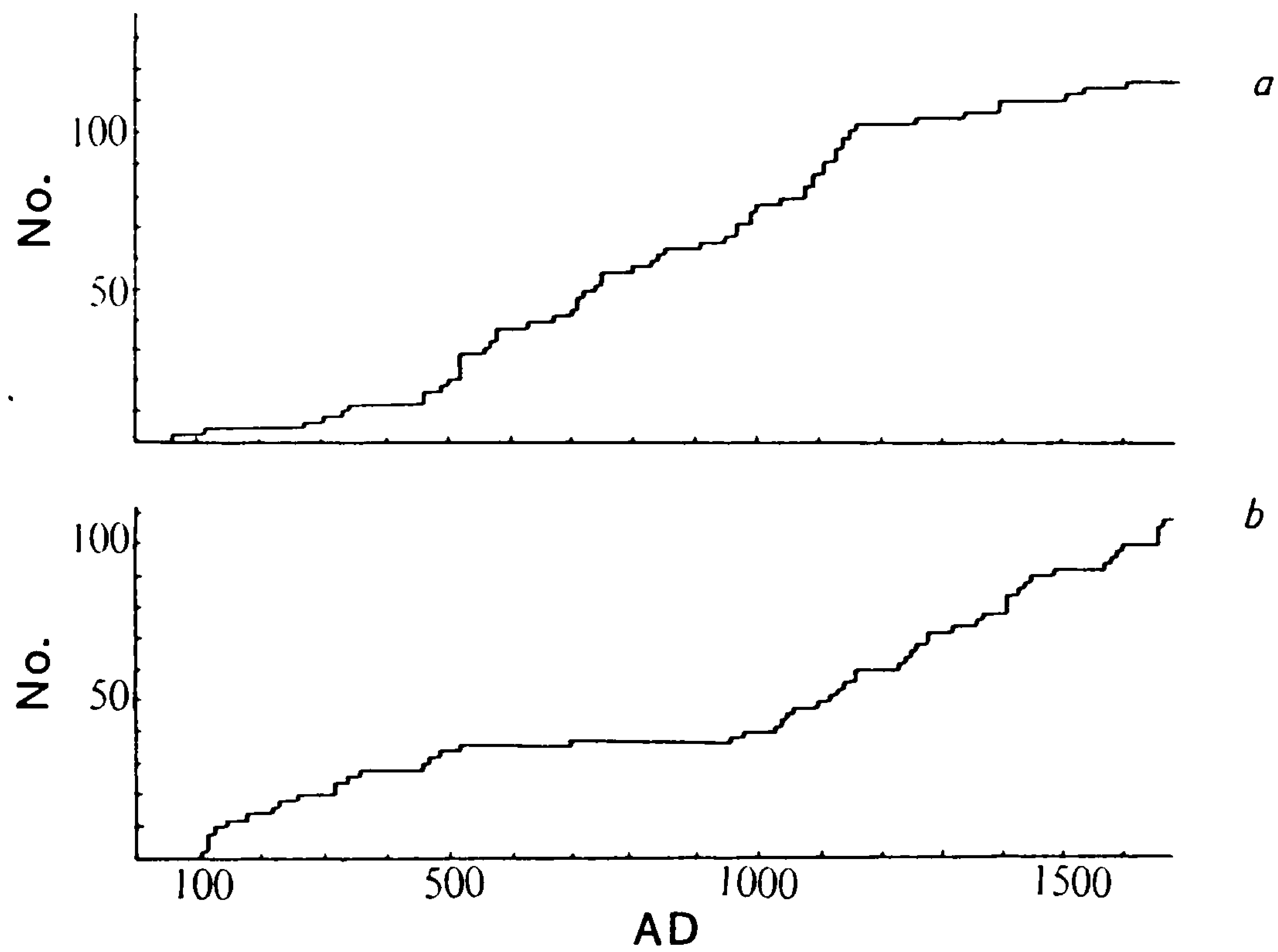
In contrast, Poirier and Taher (1980) have suggested that the lull of activity in Iraq from the end of the 13th century onwards is due to the sacking of Baghdad by the Mongols in 1258 AD. According to them, information from chroniclers in Baghdad came to an end after this date. Beaumont et al. (1976) have shown that the Mongols made repeated destructive incursions into south-west Asia during the 13th and 14th centuries. During the 16th and 17th centuries, Turkey and Persia engaged in a succession of long and exhausting wars which left much of Iraq in a state of ruin. The lull in seismic activity recorded in Iraq between the 13th and 18th centuries, could therefore be attributed to this period of prolonged instability.

As mentioned previously, the frequency histogram for Egypt is almost completely the opposite of those for the Levantine countries and Iraq (see Section 6.4.1). It seems rather unlikely that this should have occurred entirely by chance. The observed upsurge of activity in Egypt during the 10th century is difficult to explain as being anything but genuine, as is the lull during the 11th and 12th centuries. It is possible that increased activity between the 14th and 16th centuries can be attributed to the presence of two important chroniclers working in Cairo. Al Maqrizi lived in the city between 1360 and 1442 AD, and As Soyuti between 1455 and 1505 AD (see Section 5.3). Between them they provide the bulk of present-day source material concerning earthquakes in Egypt from 712 AD to 1499 AD.

Again, however, this explanation is not entirely acceptable. According to Ambraseys (1961), As Soyuti completed his work somewhere between 1499 and 1505 AD. However, Figure 6.1 clearly shows that the period of increased seismic activity in Egypt continued well beyond this date, until the start of the 17th century. In addition, Cairo was devastated by a plague in 1492 AD

Figure 6.2

The time distribution of damaging earthquakes in the Border zone (*a*) and Anatolian zone (*b*)



After Ambraseys (1971, p.379)

(Beaumont *et al.*, 1976). If anything, the documented history of the country might therefore be expected to be relatively poor during this particular period.

To conclude this sub-section, it would seem that the fluctuations in the recorded historical seismicity of the countries in the eastern part of the region cannot entirely be explained in terms of the quality of the historical record. It is therefore possible that some of them may be due, in part, to genuine periods of increased or decreased activity along tectonic zones in the region.

6.4.2.2 Explaining the histograms in terms of tectonics

Ambraseys (1971) has been able to show that in parts of the Middle East, patterns of earthquake activity have changed through time. Using historical earthquake data, he has demonstrated that the Anatolian Zone (North Anatolian fault system) has alternated with the Border Zone (East Anatolian fault system) in long periods of inactivity (see Figures 4.2 and 5.5). Figure 6.2 shows that during the first five centuries AD, the Border Zone was comparatively quiescent, while the Anatolian Zone was active. During the following six centuries the pattern was reversed, only to be reversed again during the 12th century, with a few centuries of overlapping activity.

The present analysis has just shown that like the Border Zone, the countries along the Dead Sea fault system (countries of the Levant) experienced considerable seismic activity during the 6th to 12th centuries AD. The peak of earthquake activity observed in the

Levantine countries during the 12th century, corresponds to a final burst of activity that was observed in the Border Zone at this time (see Figure 6.2). Similarly, the quiescent phase along the Border Zone which commenced in the 13th century, is matched by a relative lull of recorded activity in the region of the Dead Sea fault system.

This close correspondence of fluctuations in activity along the two fault systems suggests that they may be working in unison. To some extent this might have been expected. This is because the Dead Sea fault system and the Border Zone form an almost continuous tectonic belt along the western margin of the Arabian plate (see Figure 4.2). Slip along the plate boundary might therefore be expected to produce periods of increased earthquake activity in both tectonic zones at the same time. In addition, it would lead to an accumulation of strain in the collision zones of north Anatolia. This strain would subsequently be released by phases of increased activity in the Anatolian Zone. Such a pattern of tectonic interaction, may help to explain why the historical record suggests that periods of increased earthquake activity along the Border Zone and Dead Sea fault system, have alternated with similar periods along the North Anatolian fault system.

It is possible to extend the concept of fluctuations in seismic activity between contiguous tectonic units, to explain the frequency of historical earthquakes in Egypt. As already mentioned, Egypt experienced a peak of earthquake activity during the 14th, 15th and 16th centuries, at a time when a relative lull in activity was observed in the countries of the Levant (see Section 6.4.1).

In Section 6.2.1 it was shown that Egypt is particularly vulnerable to earthquakes generated in the Mediterranean and Red Sea tectonic zones. Ambraseys (1978) has demonstrated that there is no evidence for cyclical earthquake activity in the eastern Mediterranean basin, where "large intermediate earthquakes seem to occur almost continuously with a remarkable regularity" (p.204). It is unlikely, therefore, that the fluctuations in the historical seismicity of Egypt were due to variations in the incidence of earthquakes in the eastern Mediterranean basin. This is reinforced by analysis of the records of earthquake damage in Cairo and Alexandria (the two largest cities of the Nile delta region). The historical catalogue shows that earthquakes in the Mediterranean have frequently affected Alexandria because it is situated on the northern coastline of Egypt. However, only the largest Mediterranean earthquakes have caused damage in Cairo because of its inland location.

In contrast, large earthquakes in the extreme northern Red Sea region have invariably affected Cairo, but not Alexandria. As Kebeasy et al. (1981) have pointed out, the thick sediments of the Nile delta serve to protect Alexandria from earthquakes in the Red Sea region; the loose sediment greatly impedes the passage of earthquake shock waves.

The catalogue shows that of the 24 earthquake records for Egypt in the 15th and 16th centuries, only 1 refers to damage in Alexandria but 17 refer to Cairo. This would seem to suggest that the earthquakes either originated along faults beneath the Nile delta itself (close to Cairo), or in the northern Red Sea/Gulf of Suez region. Further analysis shows that several of the earthquake reports also refer to damage in Arabia, Israel and Sinai (e.g. events on March 18, 1481 and January 14, 1588). This suggests that (for the larger events at least) the epicentral area was in the northern Red Sea region, probably along the Gulf of Suez or its suggested extension beneath the Nile delta (see Figure 4.2 and Section 4.4.2).

If this interpretation of earthquake activity in Egypt during the 15th and 16th centuries is correct, it implies that in the past not only has seismicity fluctuated between the North Anatolian fault zone and the Dead Sea fault system, but that it has also fluctuated between the latter and the northern part of the Red Sea rift. Presumably, periods of increased activity along the length of the Red Sea rift (causing crustal separation), would induce strain along the Dead Sea transform fault system. This would subsequently be released by increased earthquake activity along the transform fault. A knock-on effect of seismic activity between contiguous tectonic units is implied.

Confirmation or rejection of these suggested patterns of earthquake activity obviously requires further detailed investigation of the historical seismicity of the region. It is, however, interesting to note that during the 20th century the Red Sea region has experienced considerable seismic activity, as earthquakes at Shadwan (1969) and Dhamar (1982) have shown (see Table 3.6). In contrast, the Dead Sea fault system has been unusually quiescent, particularly in its northern sections (i.e. those in Syria - see Figure 4.1). The North Anatolian fault system is currently experiencing a cycle of activity which commenced with a large earthquake in December, 1939 (Gutenberg and Richter, 1954).

The question to be asked, therefore, is whether or not a continuation of some age-old pattern of tectonic activity is now being witnessed in the region?

6.4.3 Implications of temporal fluctuations in seismicity for earthquake hazard assessments

If the temporal fluctuations in the earthquake activity of Middle Eastern countries are due to tectonic influences, they could have important implications for earthquake hazard assessment in the region. Not least of all, this is because they would imply that the present distribution of Middle Eastern seismicity need not necessarily correspond to that which will occur in the future. Assessments of earthquake hazard based on 20th century data alone will therefore be inherently inaccurate. They will, for instance, assign negligible earthquake hazard to the Syrian section of the Dead Sea transform fault system. This is because of the absence of significant earthquake activity along this section of the fault during the past 80 years (see Figure 4.1). Examination of historical data, however, suggests that the Syrian fault system has been one of the most active onshore tectonic zones in the entire Middle East (see Section 5.5.2.2).

Consequently, it is only through detailed analysis of the complete record of earthquake activity in the Middle East (i.e. records of historical and 20th century earthquakes), that a precise evaluation of the distribution of earthquake hazard in the region can be made.

This chapter has presented such an analysis using the data that are currently available.

6.5 CONCLUSIONS

In this chapter, the most important findings of a regional analysis of earthquake hazard in the Middle East have been presented. This analysis has involved:

a) investigations of 20th century seismicity, integrated with an analysis of regional tectonics (Chapter 4);

b) an examination of the historical seismicity of the region (Chapter 5).

The present chapter has combined evidence drawn from these two data sets, to present a comprehensive assessment of the distribution of earthquake hazard in the Middle East. This has enabled the areas of greatest earthquake hazard to be identified. These are:

- the coastal margins of the eastern Mediterranean;
- the Levant region;
- the Mesopotamian plains of Iraq, and the Zagros foothills of the northern and eastern parts of the country;
- the margins of the Red Sea, particularly the western side of the Arabian peninsula;
- the Nile delta region of Egypt;
- the northern and littoral regions of Morocco, Algeria, Tunisia and Libya.

Areas of negligible earthquake hazard include:

- the central and eastern parts of the Arabian peninsula;
- south-western and western Iraq;
- eastern Syria and Jordan;
- the southern margins of Morocco, Algeria and Tunisia.

By relating this assessment of earthquake hazard distribution to the distribution of major towns and development projects in the Middle East (as reviewed in Chapter 3), it has been possible to identify areas where the risk of earthquake-induced losses is greatest. These include:

- the Levant region, where the potential for large earthquake loss accumulations is probably greater than in any other part of the Middle East;
- the Mesopotamian plain and Nile delta;
- the western coastal margin of Saudi Arabia, and the Gulf of Suez region;
- the coastal and northern parts of the North African countries.

In many of these areas, vulnerability to earthquake hazard is escalating. This is due to the tendency towards increased heights of construction in modern Middle Eastern cities.

In addition to analysing the distribution of earthquake hazard in the Middle East, the chapter has included an analysis of temporal aspects of seismicity in the region. Evidence for variations in the earthquake activity of different Middle Eastern countries through time has been examined. It has been suggested that these variations may be related to fluctuations in activity between contiguous tectonic units in the region. They can possibly be taken to explain the recent lull in seismicity observed along the Dead Sea fault system (especially in Syria), in contrast to the activity observed in the Red Sea region.

All in all, the historical data serve to emphasise that studies of earthquake hazard based on 20th century data alone will be inherently inaccurate. This is especially the case in a region like the Middle East, where rates of seismic activity are not particularly high, and where the tectonic situation is complex. Clearly, it is only through detailed examination of what has happened in the past, that improved estimates can be made of what the future holds in store.

MIDDLE EASTERN HAZARD ANALYSIS (PART B)

- ZONING HAZARDOUS PARTS OF THE REGION FOR INSURANCE PURPOSES

CHAPTER 7. EARTHQUAKE HAZARD ZONATION - EVOLUTION OF A TECHNIQUE

7.1 INTRODUCTION

In Part A of the Middle Eastern hazard analysis, a regional examination of the distribution of earthquake hazard was presented using recent (20th century) and historical earthquake data. Areas that are particularly vulnerable to earthquakes (and associated hazards) were identified. Within these areas, every precaution needs to be taken to mitigate earthquake hazard.

Experience gained from the 1985 Mexican earthquake (Chapter 2) has shown that a primary step in the mitigation of earthquake hazard is the production of reliable hazard zonations. The purpose of Part B (Chapters 7 and 8) of the Middle Eastern analysis, therefore, is to describe (and apply) a technique of earthquake hazard zonation that has been developed during this study for use in the region. A prerequisite of the technique was that it should enable the production of zonations that satisfy the specialist requirements of the insurance industry. In addition, it should form (if possible) the basis for a global scheme.

The present chapter begins with a definition of certain key terms. Subsequent to this, general concepts of earthquake hazard zonation are outlined, and a brief review of current approaches to the problem is presented (the advantages and disadvantages of these are discussed). The specialist requirements placed by the insurance industry on earthquake hazard zonations are then summarised, and existing attempts to zone the hazard for insurance purposes are compared and evaluated. In the light of this discussion, an improved technique of earthquake hazard zonation (the R.O.A. scheme) is presented. It is shown how this can be used to derive more accurate zonations than those that are currently available to the insurance industry.

The R.O.A. scheme is applied to a Middle Eastern country in Chapter 8 (and fully evaluated).

7.2 HAZARD OR RISK?

Considerable confusion surrounds the definition of the terms "earthquake hazard" and "earthquake risk". These terms are to be used a great deal in Chapters 7 and 8. They were briefly defined in Section 1.5, but in order to avoid ambiguity are discussed in greater detail below:

7.2.1 Earthquake risk

The definition of earthquake risk is by no means uniform. It varies, not only between academics, but also between professional bodies such as engineers and insurers. Karnik and Algermissen (1978) have provided a useful review of the various interpretations of earthquake risk that are in common use.

In the U.S.S.R. earthquake risk includes "economic and other effects of earthquakes during a long time interval" (Karnik and Algermissen, 1978; p.44). Similarly, the United Nations Disaster Relief Organisation (UNDRO) define earthquake risk as the "expected number of lives lost, persons injured, damage to property and disruption of economic activity", due to a particular earthquake event (as reported in Friedman, 1984; p.125). Such a definition implies that economic considerations are an integral part of any earthquake risk assessment.

In contrast, Algermissen and Perkins (1972) and Lomnitz (1974), take earthquake risk to mean the probability of an event occurring at a specific location in a given interval of time. Donovan (1973) also concludes that earthquake risk need not take economic effects into consideration, but should be expressed merely in terms of return periods of intensity or magnitude. Kim (1983) summarises this interpretation of seismic risk as "the odds at which a specified earthquake magnitude and/or acceleration would be exceeded at a site of interest within a given time span" (p.19).

In keeping with the insurance-oriented theme of this study, the UNDRO definition of earthquake risk has been adopted. The term will therefore only be used when discussing the possibility of losses arising as a result of earthquake events. Clearly, a large earthquake in a remote, uninhabited area presents minimal threat of human or economic loss. To refer to such an area as one of high earthquake risk would therefore be non-sensical in the present context. As Bolt et al. (1975) have succinctly stated, "risk takes a cogent meaning only when the geological information is combined with the social and economic circumstances" (p.286).

7.2.2 Earthquake hazard

The terms earthquake hazard and earthquake risk are unfortunately used synonymously by many people. To some workers, the definition of earthquake hazard would be similar to that of earthquake risk given above. For instance, Bolt et al. (1975) state that earthquake hazard "is a strong function of the population density" (p.291). Smolka and Berz (1981) have defined hazard according to the equation:

Hazard = Risk x Vulnerability

Here the term earthquake hazard is restricted to descriptions that concern the distribution, severity and frequency of the natural phenomena, without making reference to economic or social considerations.

7.2.3 Earthquake hazard and risk maps

In accordance with the above definitions, risk maps are herein regarded as maps which provide information on the extent and probability of earthquake inflicted losses. For example, a map which divides a country into zones on the basis of the amount of expected earthquake damage is a risk map. Similarly, a map which zones a city according to the amount and type of earthquake damage to be expected in "x" years is a risk map. Both maps serve to compare the distribution of expected earthquake effects, with the distribution and vulnerability of population and constructions to these effects.

Hazard zonation maps are those which are based solely upon geological information, and attempt to show the expected severity/frequency of earthquakes. For example, maps which show the probability of recurrence of earthquakes in a region, and/or the severity of ground motion to be expected. These maps do not attempt to determine the probability or forecast the extent of losses that can be expected as a result of earthquakes.

From such definitions, it is apparent that an evaluation of earthquake hazard must precede any attempt at earthquake risk analysis. The remainder of this chapter is therefore devoted to earthquake hazard zonation.

7.3 EARTHQUAKE HAZARD ZONATION - GENERAL CONCEPTS

In recent years considerable advances have been made in the prediction of earthquake events. However, at present no reliable earthquake early warning system is in operation. Even if such a system were to come into operation, it would be of limited benefit to the insurance industry. Admittedly losses in some sectors (e.g. life insurance) would be reduced, but earthquake warnings can do little to prevent damage to buildings that have already been erected in hazardous areas.

The only reliable way to reduce the economic losses attributable to earthquakes, is by adopting the preventative approach provided by hazard zonation. This gives a sound basis for the location and protection of buildings, through the development of zoning regulations and building codes.

In order to zone earthquake hazard, it is necessary to identify the geological factors which are the major cause of damage during earthquakes. These are:

a) Ground vibration;

b) Ground deformation (e.g. faulting);

c) Liquefaction and settlement;

d) Slope failure;

e) Flooding.

Of these factors, only the first two are directly related to crustal movements. The remaining three are indirect effects, caused by the response of the ground to inputs of energy from seismic shock waves. Despite this, factors (c), (d) and (e) often cause the majority of the damage that is experienced during earthquakes (as shown by the historical records of earthquake damage in the Middle East - see Section 5.7).

The amount of consideration paid to each of these major causes of earthquake damage varies according to the scale and technique of hazard zonation used. Most earthquake hazard zonations adopt one of two possible approaches:

- macrozonation;
- microzonation.

7.3.1 Macrozonation

Macrozonation is hazard zonation at a relatively small-scale.

Macrozonation maps serve as general hazard maps, from which it is necessary to pass to microzonation maps for more detailed information.

Due to the small scale of mapping used in macrozonations, considerable generalisation has to be made when producing hazard maps of this type. As a result, macrozonations seldom take into consideration the influence of local soil conditions, or engineering problems of soil-structure interaction. The earthquake tariff zones of Mexico shown in Figure 2.25 are based upon a macrozonation of earthquake hazard in the country.

Clearly, of the five factors that contribute to earthquake damage (as listed above), only the first factor (vibration) should be included in earthquake hazard macrozonations. Problems of scale mean that the remaining four factors can only be incorporated in microzonations.

7.3.2 Microzonation

The choice of scale used in the production of microzonations varies depending on the amount of detail required. Typically it is between 1:5,000 and 1:200,000 (Verstappen, 1981).

According to Ziony (1985), microzonation is the "geographic delineation on a regional or local scale of areas having different potentials for hazardous effects of earthquakes (including geologic effects such as surface faulting, strong ground shaking, and ground failure)" (p.18). The content of microzonation maps varies slightly, but one element common to all is the fact that they attempt to show the effect of ground variation from point to point. The earthquake tariff zones of the Federal District of Mexico City shown in Figure 2.8 are based upon a hazard microzonation of the city (see Section 2.6.1).

Steinbrugge (1978) states that the following geological hazards, if present, should be identified on all earthquake microzonation maps:

a) Active fault traces;

b) Potential landslide areas;

c) Areas of structurally poor ground (e.g. marshes).

Microzonation is only possible where large-scale geological maps are available. Detailed geotechnical data are also often required. Verstappen (1981) has shown that geomorphological mapping can be of great value in the production of microzonations. This is because geomorphology can provide valuable information concerning geology, subsoil conditions and slope stability.

7.4 EXISTING METHODS OF EARTHQUAKE HAZARD ZONATION

The results of earthquake hazard zonation are applied in a variety of ways (e.g. engineering, land-use planning, insurance, and emergency preparedness and response). As a result, the types of zonation map produced show considerable variation in content, and in the techniques that have been used in their compilation.

7.4.1 Parameters used in zonations

The choice of which parameter(s) to use in a zonation varies according to the information available, and the intended use. The following parameters are the ones most commonly used in earthquake hazard zonations:

- Macroseismic intensity;
- Ground motion (acceleration, velocity etc.).

7.4.1.1 Macroseismic intensity

The intensity scale is based on descriptions of the effects that earthquakes have on the surface of the earth, and on man and his constructions. Due to the fact that it is defined by macroseismic effects, intensity provides a qualitative, non-instrumental measurement of the severity of earthquake ground motion. It is strongly affected by personal judgement and other influences. As a result, use of the intensity scale in quantitative studies is strictly limited.

Various intensity scales have been developed, but (as already mentioned) the one that has been adopted for use in this study is the Modified Mercalli scale (MM) of 1956. Table 5.1 shows that this scale has twelve divisions (indicated by Roman numerals).

The advantage of zoning on the basis of observed intensity is that "it is the only quantity widely available throughout the world that can be used as a measure of ground motion" (Algermissen and

Steinbrugge, 1984; p.24). In addition, the use of intensity enables the effects of earthquake focal mechanisms, wave propagation, wave attenuation and site conditions to be included in the final assessment (Karnik and Algermissen, 1978). This is despite the fact that quantitative data on each of these effects may not be separately available. Historical earthquake data can also be included in the hazard analysis when intensity is used.

7.4.1.2 Ground motion (acceleration, velocity etc.)

Due to the ambiguity of intensity scales and the difficulty of interpreting them, it is often necessary to prepare more quantitative maps that can be related directly to engineering design. Consequently, zonations based on parameters such as peak acceleration, peak particle velocity, predominant period of motion and spectral density have been produced. In hazard zonations that are to be used for engineering purposes, seismic coefficients of this type are often related to building codes.

The production of quantitative maps is often hindered by a lack of necessary data. Information concering earthquake frequency and distribution, earthquake focal mechanisms, wave attenuation and site response is often lacking. Values of acceleration and velocity have not, as yet, been widely recorded throughout the world. The great majority of instrumental strong-motion data that are available have been recorded in California (USA) and Japan. Their use in other parts of the world is limited.

Lack of available quantitative data is a major problem that hinders the development of a zoning technique for application in the Middle East.

7.4.2 Types of earthquake hazard zonation

According to Karnik and Algermissen (1978), two main types of earthquake hazard zonation exist:

- Deterministic zonations;
- Probabilistic zonations.

7.4.2.1 Deterministic hazard zonations

Deterministic hazard zonations show the distribution of observed or expected earthquake effects. Hence, the maps of historical earthquake activity in the Middle East presented in Chapter 5, are examples of this approach to hazard zonation in its simplest form (see Figures 5.4 and 5.10). More precise zonations provide an estimation of the maximum severity of ground motion that has been observed, or is expected. The assessment is usually in terms of intensity (e.g. Roussel, 1973), though quantitative parameters have also been used in deterministic zonations (e.g. Karnik 1969; 1971).

A major disadvantage of the deterministic approach is that it results in a "static" zonation which provides no information concerning frequency of occurrence (Bolt et al., 1975). Hence, a region that experiences a maximum earthquake intensity of IX once in 400 years, is given an identical hazard rating to one experiencing the same intensity once every 50 years. This obviously provides a misleading impression of the true nature of the earthquake hazard. One way of overcoming this problem is to adopt a probabilistic approach to hazard zonation.

7.4.2.2 Probabilistic hazard zonations

There is often a need to express the parameters of an earthquake hazard zonation in probabilistic terms. Probabilistic hazard maps provide an indication of return periods for different severities of earthquake ground motion.

The importance of recurrence data in hazard zonations is becoming increasingly apparent. For example, Karnik and Algermissen (1978) report that in certain types of structure, greater cumulative damage results from the more frequent moderate earthquakes than from the occasional large shock. A probabilistic approach to hazard zonation enables infrequent but catastrophic earthquake events to be given proper weighting, relative to those that are much more frequent but less damaging.

7.5 ZONING EARTHQUAKE HAZARD FOR INSURANCE AND REINSURANCE PURPOSES

Until the 1970's, insurers and reinsurers concerned with providing earthquake coverage, were very much dependent upon hazard zonations produced for a variety of purposes other than use by the insurance industry. These zonations were often not particularly well suited to specialist insurance requirements. During the past ten years, there has been an increasing awareness of the need to produce insurance-oriented earthquake hazard zonations. This has been reflected in the large number of publications concerning this aspect of natural hazards research that have been produced by the major insurance and reinsurance companies.

7.5.1 Specialist requirements placed by the insurance industry on hazard zonations

According to Richter (1959) and Smolka and Berz (1981), the best zonations for insurance purposes are those which satisfy the following criteria:

a) Assessment in probabilistic terms

A probabilistic approach to earthquake hazard mapping is preferable to a deterministic one. An insurance earthquake zonation should give information on both the size and frequency of earthquake events to be expected. From this, insurers can then calculate the magnitude of earthquake losses that are likely to occur over a given time period, and derive earthquake premiums that are commensurate with the risk.

b) Use of intensity as the zonation parameter

At a time when an increasing number of earthquake hazard zonations are using quantifiable parameters such as acceleration and velocity, macroseismic intensity remains the most appropriate parameter for mapping earthquake hazard from the insurance point of view. According to Smolka and Berz (1981), the main reason for this is that most earthquake loss statistics take intensity as the reference parameter. For example, those of the Munich Re. (1978) and Sauter et al. (1980). Since loss statistics form the basic input in the calculation of earthquake premiums, it would obviously make no sense whatsoever to prepare a hazard map for insurance purposes that could not be related to them.

As mentioned in Section 7.4.1.1, intensity is subjective by nature, and is by definition linked to loss extent. However, several arguments can be put forward to support the use of intensity in insurance zonations:

- It is the only measure available which integrates numerous damage factors. These include the spectral characteristics and duration of the earthquake ground motion, and its severity. The importance of these factors in controlling the amount of building damage experienced during an earthquake was highlighted in Sections 2.10.2 and 2.10.3;

- By using intensity, historical earthquake data can be incorporated in the hazard analysis. Data of this type make it possible to extend the length of time for which a statistical analysis can be undertaken. This is of great importance to insurers, who frequently are concerned with the analysis of extreme, but rare, earthquake events;

- As mentioned in Section 7.4.1.2, strong ground motion measurements (instrumental data) are of very limited availability at present. In contrast the intensity scale is universally applicable, and can be used to produce analogous zonations for different countries around the world.

7.5.2 Comparison of some existing zonations of earthquake hazard for insurance purposes

Of the earthquake hazard zonations that have already been developed by insurance and reinsurance companies, few have satisfied the requirements listed in Section 7.5.1. The following discussion is restricted to the zonations that have been developed in recent years, and applied globally.

In 1978, the Commercial Union Assurance Company (C.U. Assurance) described a technique of earthquake hazard zonation. They produced a report which attempts "to indicate the regions of the world which are most subject to earthquakes and in which this risk should be most cautiously underwritten" (C.U. Assurance, 1978; p.6). The report contains two types of earthquake hazard map:

a) A general map showing all the earthquake belts of the world. These belts are shaded according to relative rates of seismicity (based on crude assessments of frequency and size of events);

b) Eight regional maps of greater detail. On these maps, a colour code system is employed to indicate relative exposure to earthquake hazard. Six exposure zones are used, ranging from "negligible exposure" to "very high exposure". An additional shading pattern is used to indicate the level of insured damage likely.

The C.U. Assurance zonation has to its advantage the fact that it is simple to understand, and easy to use. However, it is of limited value to the insurance industry because it fails to satisfy either of the two criteria listed in Section 7.5.1. In particular, the maps fail to assess the severity of the hazard in terms of a meaningful parameter. Their interpretation is therefore subjective and open to error. In addition, the maps provide no data concerning the frequency of earthquake occurrence. It is, therefore, theoretically possible for the same colour coding to apply to an area where earthquakes are very infrequent but extremely destructive, and an area where frequent earthquakes occur causing only small amounts of damage.

In 1978, the Swiss Reinsurance Company (Swiss Re.) published an "Atlas on Seismicity and Volcanism". The purpose of the atlas was to provide a simplified summary of the vast amount of data available concerning earthquake and volcanic activity around the world.

The atlas comprises ten regional maps, and a catalogue of significant earthquake and volcanic events. On the regional maps earthquake hazard is graded into four zones on the basis of "event probability and loss caused". The zones range from "low exposure" to "very heavy exposure". In addition, the epicentres of some significant historical and recent earthquakes are marked on the maps.

Once again, the Swiss Re. system fails to satisfy the specific zonation requirements of the insurance industry. The assessment of earthquake hazard is made in relative terms rather than using a specific earthquake parameter, and earthquake probability is not considered.

In 1978, the Munich Reinsurance Company (Munich Re.) produced a "World Map of Natural Hazards". The map and accompanying booklet provide the most comprehensive approach to earthquake hazard zonation (and risk evaluation), so far developed for insurance and reinsurance purposes. The booklet gives a thorough description of the zonation technique, and shows how to apply the map.

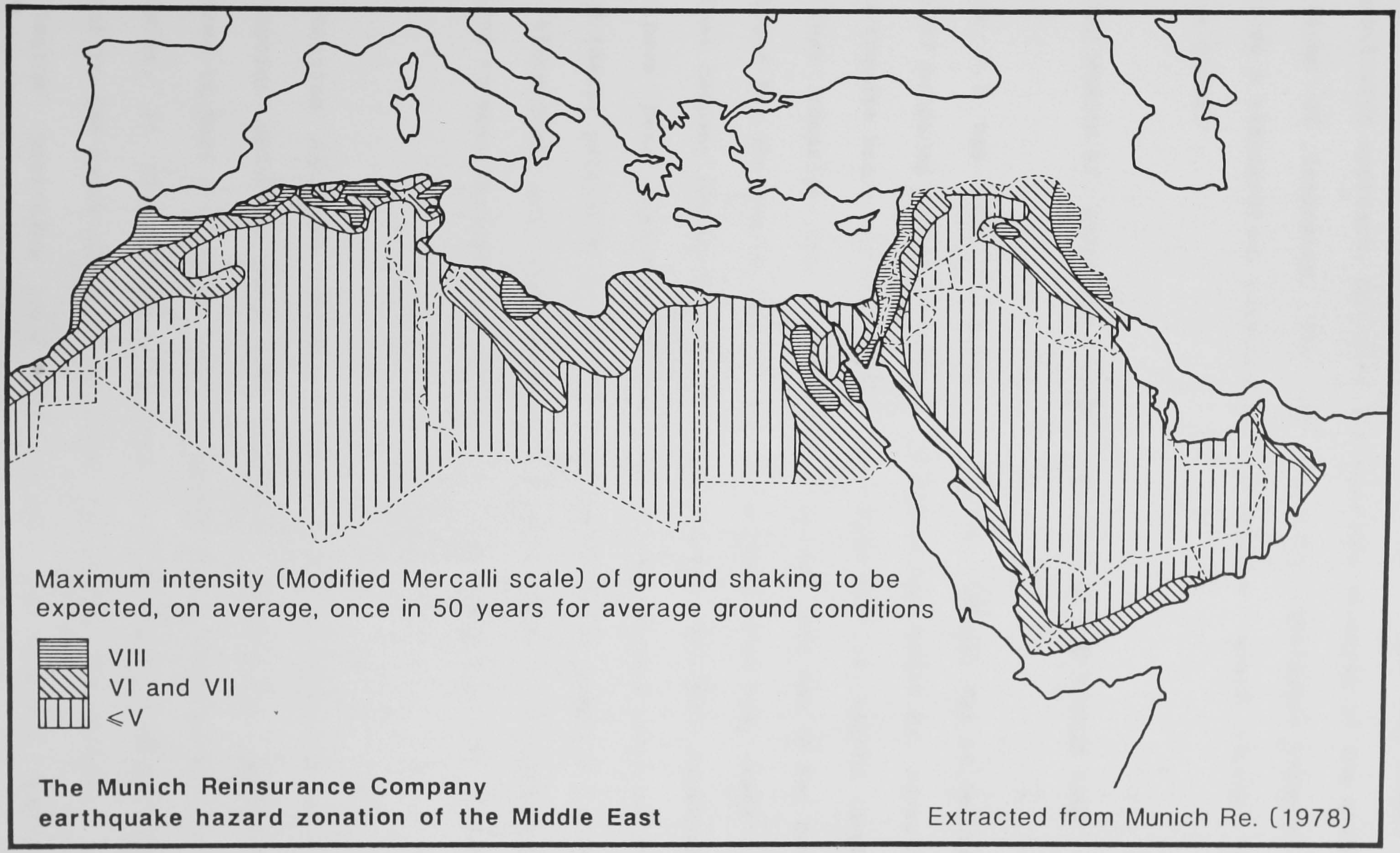
The Munich Re. zonation system assesses earthquake hazard in terms of the probable maximum intensity (Modified Mercalli scale) of ground shaking to be expected, on average, once every 50 years. Four exposure zones are identified on the land areas of the map, and defined as follows:

Zone	Maximum intensity (to be expected once in 50 years)
0	<=V
1	VI or VII
2	VIII
3	>=IX

Due to the small scale of mapping used in the production of the Munich Re. map (1:30,000,000), the exposure values given correspond to the severity of shaking that is to be expected in areas of "average ground conditions". These are defined as consolidated sediments, such as limestone or sandstone. Deviations in surficial geology from this "average" will therefore lead to considerable variations in exposure that are not shown on the map.

Despite this, the earthquake zonation produced by the Munich Re. is

Figure 7.1



The Munich Reinsurance Company earthquake hazard zonation of the Middle East

a marked improvement upon previous attempts to zone earthquake hazard for insurance and reinsurance purposes. It not only adopts a probabilistic approach, but also assesses the severity of the hazard in terms of intensity. The map is also invaluable because it provides a standardised zonation of earthquake hazard across the entire globe.

7.6 THE MUNICH RE. EARTHQUAKE HAZARD ZONATION OF THE MIDDLE EAST

Figure 7.1 has been extracted from the "World Map of Natural Hazards" produced by the Munich Re. It shows the Munich Re. zonation of earthquake hazard in the Middle East. This map is beyond doubt the best zonation (for insurance purposes) that has so far been developed for the region as a whole. It is based upon many years of original company research, but also incorporates data from zonations that have been produced by other workers for various parts of the region (Berz, pers.comm.). As such, the map has been compiled using both historical and instrumental earthquake data. It is currently employed by most insurers and reinsurers that operate in the Middle East.

The zonation compares favourably with the impression of hazard distribution obtained from the regional earthquake analysis presented in Part A of this study (as summarised in Section 6.5). In particular, it clearly shows that the areas of greatest hazard lie adjacent to the major tectonic units of the region. For example, in the Zagros mountains (and Mesopotamia), the western Arabian peninsula, the Levant and Dead Sea rift region, the Nile valley and delta (and eastern Egypt), and northern and littoral regions of

North Africa (for full discussion see Sections 6.2.1 and 6.2.2). Also in accordance with the findings of the present study, Figure 7.1 shows that the least hazardous parts of the Middle East are those in central Arabia, and in the Saharan region of North Africa.

7.6.1 Weaknesses in the zonation produced by the Munich Re.

As discussed in Section 7.5.2, Figure 7.1 provides an assessment of earthquake hazard in terms of the maximum intensity of shaking to be expected, on average, once in 50 years for <u>average</u> ground conditions (defined as sedimentary rock). The main disadvantage of this approach is that few of the major cities in the Middle East are situated upon geological foundations of this type. Instead, they tend to be built upon unconsolidated sediments associated with river valleys or coastal plains. Although such areas are more vulnerable to earthquake ground motions than solid rock, they have provided (throughout history) a number of favourable conditions for the development of large urban settlements. These include:

a) Abundance of flat land that is easily developed and provides good communication links;

b) Fertile soils that can be farmed to provide food to support large urban populations;

c) A source of water, both for human consumption and irrigation;

d) Soft foundations that are easy to excavate;

TABLE 7.1

Geological Conditions Underlying the Fifteen Largest Cities in the Middle East

Cities (ranked by population size)	Predominant Underlying Geology
1. Cairo (Egypt)	Quaternary river deposits
2. Baghdad (Iraq)	Quaternary river deposits
3. Alexandria (Egypt)	Quaternary coastal deposits
4. Damascus (Syria)	Eocene and Pliocene sedimentary units
5. Giza (Egypt)	Quaternary river deposits
6. Aleppo (Syria)	Miocene and Eocene sedimentary units
7. Tunis (Tunisia)	Quaternary deposits
8. Riyadh (Saudi Arabia)	Jurassic rock units
9. Amman (Jordan)	Cretaceous rock units
10. Jeddah (Saudi Arabia)	Quaternary coastal deposits
11. Marrakech (Morocco)	Quaternary deposits
12. Oran (Algeria)	Pliocene sedimentary units
13. Basra (Iraq)	Quaternary deposits
14. Fez (Morocco)	Quaternary deposits and Miocene sedimentary units
15. Meknes (Morocco)	Quaternary deposits and Pliocene sedimentary units

Source of data: Various geological maps of the Middle Eastern region

e) An equable environment, in the otherwise hot and dry climate of the Middle East.

Table 7.1 lists the geological units underlying the 15 largest cities in the Middle East (ranked in order of population size). Of these cities, only 2 are situated on solid rock (i.e. Riyadh and Amman). The remainder are on sedimentary units of Quaternary or Tertiary (predominantly Eocene, Miocene and Pliocene) age. The Quaternary units are almost entirely unconsolidated, whilst those of Tertiary age are, at best, poorly lithified.

The 1985 Mexican earthquake highlighted the fact that soft, unconsolidated geological foundations serve to aggravate the severity of shaking experienced during earthquakes (see Section 2.13.1). The historical earthquake catalogues for the Middle East have provided much evidence to substantiate this fact (see Section 5.8). In view of this, considerable interpolation of the data presented in Figure 7.1 is needed in order to ascertain the true exposure of many parts of the Middle East to earthquake hazard.

In order to take the effects of surficial geology into account, the Munich Re. (1978) suggest that Table 7.2 should be used in conjunction with the world map. This makes it possible to determine the severity of earthquake hazard in areas of non-average ground conditions.

Hence, to obtain a wholly accurate impression of the exposure of any particular part of the Middle East to earthquake hazard, the insurer/reinsurer must combine the Munich Re. zonation with a

TABLE 7.2

Average Changes in Intensity Associated with Different Types of Surficial Geology

Surficial Geology	Average Change In Intensity
Hard rock (e.g. granite, gneiss, basalt)	-1
Sedimentary rock and firm sediments	0
Loose, unconsolidated sediments (e.g. sand, alluvial deposits)	+1
Water-saturated sediments or artificially filled ground	+1.5

After: Munich Re. (1978; p.12)

detailed surficial geology map of that area, and apply the criteria listed in Table 7.2. Few underwriters are in a position to do this on a day to day basis. It is for this reason that improved zonations are required which serve to distinguish between areas of different hazard severity with greater accuracy.

7.7 DEVELOPMENT OF AN IMPROVED HAZARD ZONATION SCHEME (THE R.O.A. SCHEME) FOR APPLICATION IN THE MIDDLE EAST

As mentioned in Section 7.4.1.2, the amount of quantitative seismic data available for large parts of the Middle East is strictly limited. In view of this (and the limited amount of time available), it was judged inappropriate to attempt to derive completely new zonations for the region. Instead, it was decided to use the Munich Re. zonation as a base map, and to develop a technique of refining it to produce larger scale zonations of greater accuracy. The advantages of refining the Munich Re. scheme, rather than attempting to devise completely new zonations, are as follows:

a) The Munich Re. map provides an accurate impression of the regional distribution of earthquake hazard in the Middle East (see discussion in Section 7.6);

b) As mentioned in Section 7.5.2, the Munich Re. map provides a standardised zonation of earthquake hazard for the entire Middle East (and, indeed, for the whole world). It is, therefore, an ideal base map from which to work;

c) The Munich Re. scheme satisfies all the basic requirements of a zonation for insurance purposes (i.e. it adopts a probabilistic approach, and assesses the severity of the hazard in terms of intensity).

In developing a scheme that will enable more accurate hazard zonations to be produced, this study has moved away from the problems of scale that restricted the amount of detail shown on the Munich Re. map. It has therefore been possible to include some consideration of surficial geology (and its influence on the severity of the hazard) in the new zonation scheme. The way in which this has been done is as follows:

Scheme for producing a hazard zonation of any region

Stage 1

Extraction, for the region, of the earthquake hazard zones shown on the Munich Re. "World Map of Natural Hazards".

Stage 2

Compilation of a map of surficial geology in the region. This should also attempt to identify areas of poor ground (e.g. marshy areas and artificially reclaimed land).

Stage 3

Use of the surficial geology map to amend the Munich Re. zonation, using the criteria listed in Table 7.2.

Stage 4

Production of an improved hazard map. This assesses exposure to earthquake hazard in terms of the probable maximum intensity of ground shaking to be expected, on average, once every 50 years for actual ground conditions.

This technique will, from now on, be referred to as the Reinsurance Offices Association (R.O.A.) scheme. The two components of the R.O.A. scheme that are used to derive a hazard zonation are the hazard map produced by the Munich Re., and a map of surficial geology. One method of combining these is to use a grid network as the basis for the hazard zonation.

7.7.1. The grid system approach to hazard zonation

The grid system approach has frequently been used to produce hazard zonations (of various types). For example, Carrara et al. (1978) described a methodology of landslide hazard analysis based on a grid network.

In the grid system approach, each square of a grid network is assumed to represent a hazard exposure zone (hence the zones are standardised in area). Elements that serve to control the severity of the hazard are then identified. For example, in a landslide analysis these might include slope steepness, lithology and amount of water present. Values for all of the controlling elements are assigned to each grid square of the network. The severity of hazard to be expected in each unit can then be determined by combining the values of all the hazard controlling elements.

In order to use this approach in the R.O.A. hazard zonation scheme, it is necessary to transfer a map of surficial geology (for the region in question) to a grid network. If the Munich Re. zonation for the region is then transferred to an identical grid, the two can be overlaid. From the overlays, it is then possible to derive a third grid (using Table 7.2) showing exposure to earthquake hazard for actual ground conditions. This grid is the new, improved hazard zonation for the region.

7.8 LIMITATIONS OF THE R.O.A. SCHEME

The limitations of the R.O.A. scheme must be stated from the start. It can only be used to derive relatively small-scale hazard maps (macrozonations). For example, national zonations. This is because of the small scale of mapping used to denote earthquake exposure zones on the Munich Re. map (scale of 1:30,000,000). It would obviously be unwise to try to transfer these zones to a large-scale map (e.g. 1:50,000).

On the national level, the scale adopted for the production of hazard zonations can be varied slightly to suit the most accurate and recent maps of surficial geology available. Such maps vary in size, but are typically at scales between 1:500,000 and 1:5,000,000. Obviously, a larger scale map enables a more accurate zonation to be derived (i.e. one that is more locationally precise).

Another important factor to be taken into consideration when producing a zonation using the R.O.A. scheme, is the size of grid square to use. Small grid units increase the accuracy ("resolution") of the final map, but may result in an unnecessary refinement. There can be no strict guidelines concerning the most appropriate size of grid square to employ. This should be adjusted to suit the needs of the insurer/reinsurer and to take into account the accuracy and amount of local data available, whilst at the same time bearing in mind the limitations of the technique.

No matter how large or small are the grid squares used in the zonation procedure, some generalisations have to be made. This is particularly the case in areas where surficial geology is very variable. Under such circumstances, difficulties may arise in assigning ONE lithology type to each grid unit. The predominant lithology in the grid square should therefore be adopted. If different lithologies are present in equal proportions, the one associated with the severest intensity of ground motion should be used. For example, if alluvium and rock occur in equal proportions within a grid square, the alluvium should be taken as the representative geological unit. Such an approach is considered more desirable than one which underestimates the severity of the hazard.

7.9 CONCLUSIONS

In the light of the regional analysis of earthquake hazard (presented in Part A of the Middle Eastern study), the purpose of this chapter has been to describe a technique of earthquake hazard zonation that has been developed during the study for application in the region. The technique (the R.O.A. scheme) is designed to meet the specific requirements of the insurance industry.

The R.O.A. scheme is based upon a global earthquake hazard zonation published by the Munich Reinsurance Company in 1978. This assesses the severity of the hazard in terms of the probable maximum intensity of shaking to be expected (on average) once every 50 years for average ground conditions (defined as sedimentary rock). The R.O.A. scheme provides a means of refining this zonation, to take into consideration the effect that surficial geology exerts on the severity of earthquake hazard. It should therefore enable the production of more accurate hazard zonations than those that are currently available to insurers and reinsurers.

The R.O.A. scheme employs a grid system to produce hazard zonations. The Munich Re. zonation and a corresponding map of surficial geology are transferred to identical grid matrices. By superimposing these, and applying the appropriate criteria (as listed in the chapter), it is possible to derive a third grid matrix showing exposure to earthquake hazard for actual ground conditions. This is the improved hazard zonation.

Complications arise when grid units contain variable lithology. Under such circumstances generalisations have to be made, and the exposure value given is that associated with the predominant lithological type (to assign a compromise intensity rating would only lead to misinterpretation). The intensity value assigned is therefore that which can be expected across the larger part of the grid unit.

The following chapter attempts to evaluate the validity of the R.O.A. scheme. In addition, it shows how a hazard map produced according to the scheme can be used as the basis for an insurance-oriented analysis of earthquake hazard and risk in a Middle Eastern country, namely Israel.

CHAPTER 8. AN EVALUATION OF EARTHQUAKE HAZARD AND RISK IN ISRAEL

8.1 INTRODUCTION

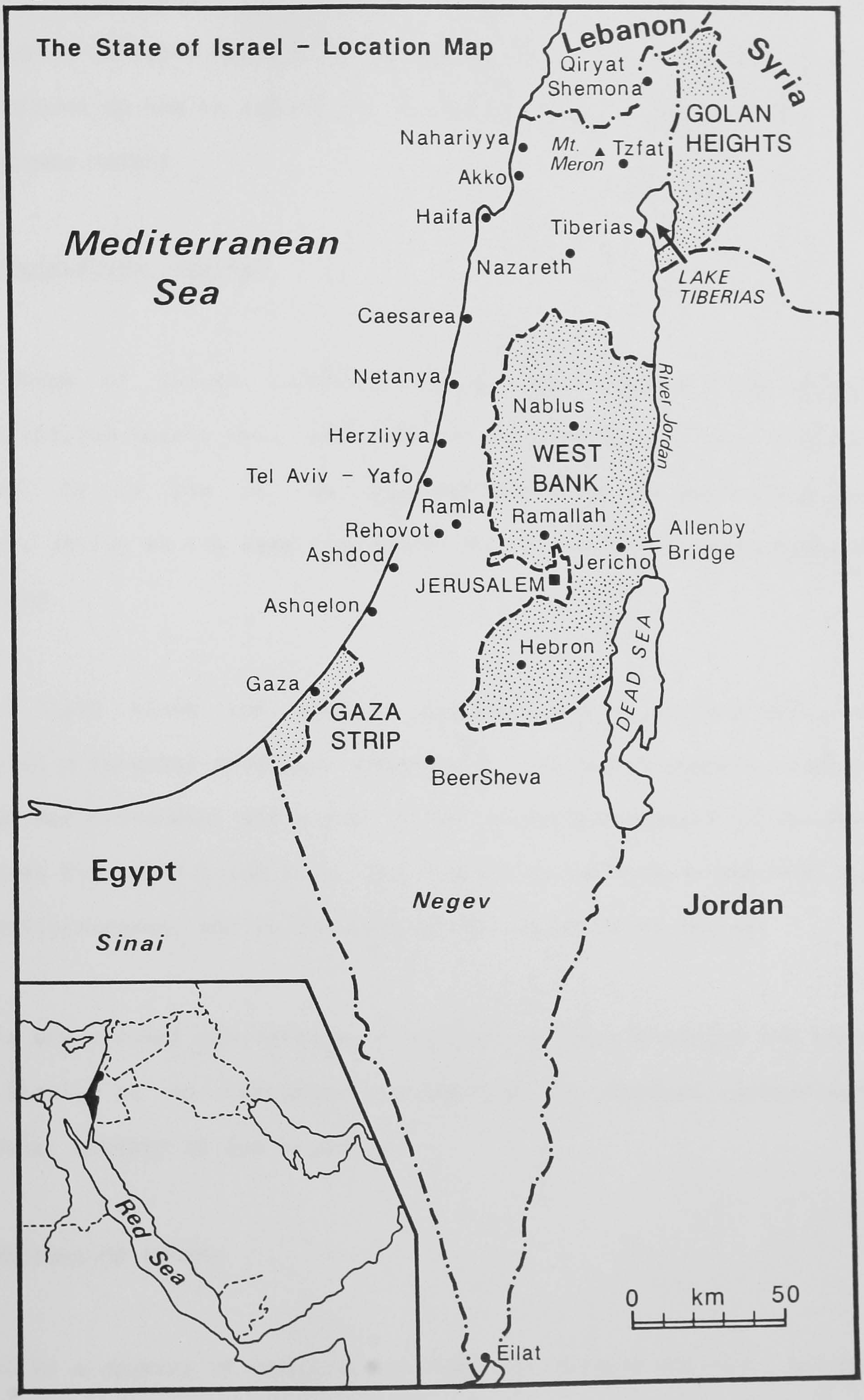
In Chapter 7, the Reinsurance Offices Association (R.O.A.) scheme for earthquake hazard zonation was described. The purpose of this chapter is to show how the scheme can be applied to produce a hazard map, which can then form the basis of an insurance-oriented analysis of earthquake hazard and risk in a country.

The country that has been chosen for analysis is Israel. This is mainly because Israel has experienced one of the highest incidences of historical earthquake activity in the Middle East (see Chapters 4, 5 and 6). In addition, the country has undergone rapid economic expansion in recent years, and is now one of the most highly urbanised countries in the world (see Chapter 3). Israel is consequently a country that is of considerable concern to the insurance industry.

The chapter begins with a brief description of the physical regions of Israel, and a review of the surficial geology of the country. Following this, an earthquake hazard zonation of Israel (produced using the R.O.A. scheme) is presented and interpreted. The validity of this zonation is examined, and it is related to important centres of population in order to delineate areas of relative earthquake risk.

The second half of the chapter includes an analysis of earthquake hazard in certain major Israeli cities. Large-scale hazard zonation

Figure 8.1


The State of Israel - Location Map
Lebanon
Syria
Qiryat Shemona
GOLAN HEIGHTS
Nahariyya
Mt. Meron
Tzfat
Akko
Haifa
Tiberias
Mediterranean Sea
Nazareth
LAKE TIBERIAS
Caesarea
Netanya
River Jordan
Nablus
Herzliyya
WEST BANK
Tel Aviv - Yafo
Ramla
Ramallah
Rehovot
Allenby Bridge
Ashdod
Jericho
JERUSALEM
Ashqelon
Hebron
DEAD SEA
Gaza
GAZA STRIP
BeerSheva
Egypt
Negev
Jordan
Sinai
Red Sea
0 km 50
Eilat

maps of some urban areas are presented, and the need for microzonation maps that show exposure to a variety of earthquake-related hazards is discussed. The chapter concludes with suggestions of how to reduce the vulnerability of Israeli cities to earthquake hazard.

8.2 GEOGRAPHICAL SETTING

The State of Israel covers an area of approximately 7,992 square miles (20,700 square km), and has a population of 4.2 million (1986). It is one of the smallest states in the Middle Eastern region, whilst at the same time being one of the most economically advanced.

Israel lies along the western fringe of the Asian land mass. It occupies a marginal position, situated in the south-eastern corner of the Mediterranean, and close to the northern extremity of the Red Sea (see Figures 3.1 and 8.1). The country is bounded in the west by the Mediterranean, and in the east by the Jordan rift valley.

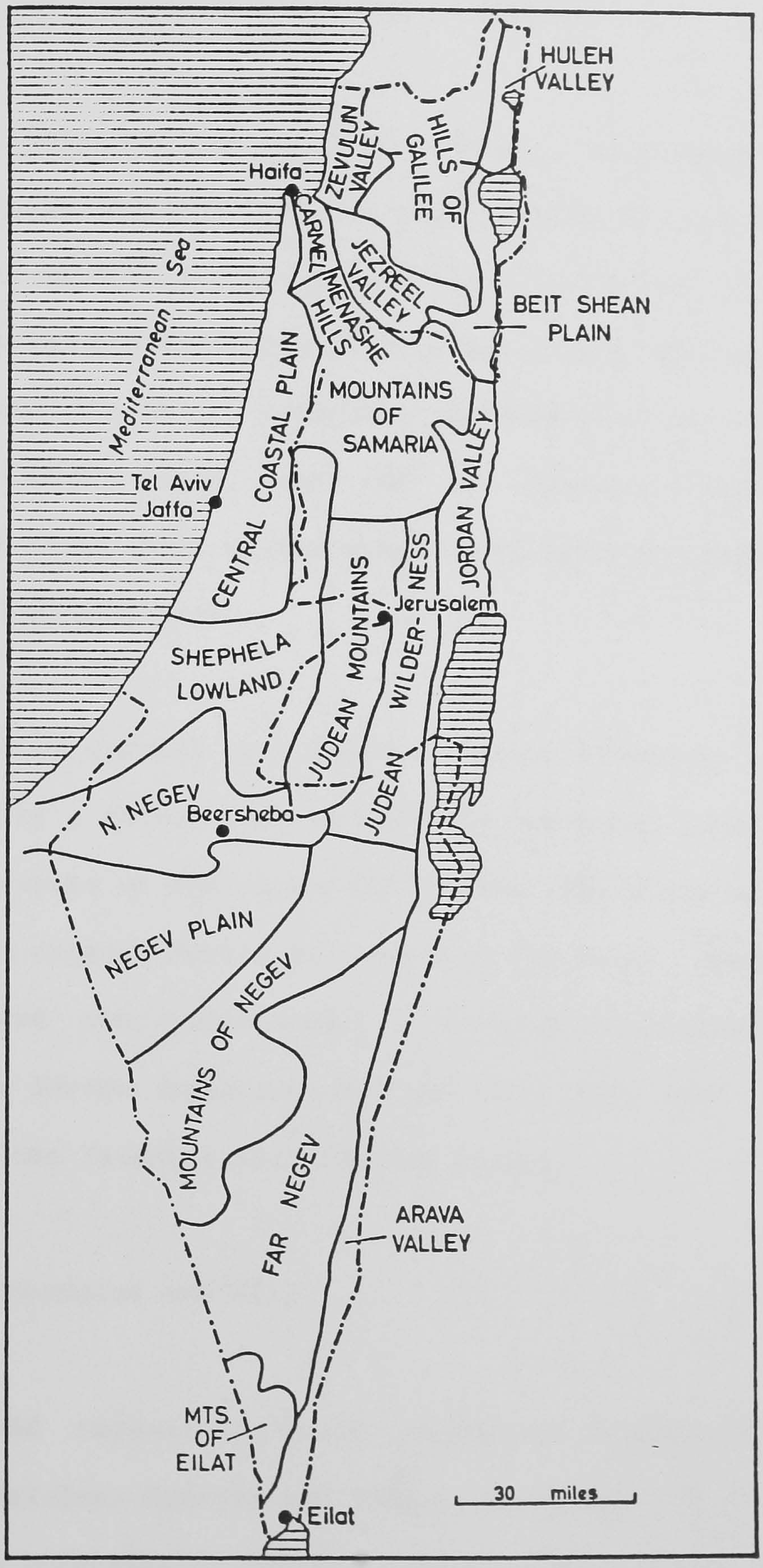
Before any attempt can be made to analyse earthquake hazard and risk in Israel, it is necessary to describe the physical regions and surficial geology of the country.

8.3 REGIONS OF ISRAEL

Israel is a country of considerable regional diversity. Each region has particular physical characteristics, some of which are of importance in controlling exposure to earthquake hazard. The major

Figure 8.2

The regions of Israel



After Tavener (1961, p.48)

regions of Israel are shown in Figure 8.2, and are discussed in detail below.

8.3.1 The coastal plain and Valley of Jezreel

The great limestone spur of Mount Carmel interrupts the Israeli coastal plain just south of the Bay of Haifa. To the north lies the small plain of Akko and the Zevulun valley. To the south are the wider plains of Sharon (central coastal plain) and the Gaza region. Nowhere along the entire coastline of Israel do the plains exceed 20km in width. Large parts of the coastal plain were formerly covered by swamp. Most of the swamp areas were reclaimed during the 19th and 20th centuries.

The Valley of Jezreel is a tectonic trough formed by subsidence. It is floored by a thick layer of alluvium weathered from the limestone and basalt rocks of the surrounding hills. The soils are dark, heavy and rich in organic matter derived from the thick swamp vegetation that covered the valley bottom until Jewish colonisation in the 1920's. The Jewish immigrants drained the land, and in doing so turned it into Israel's most fertile valley.

8.3.2 The mountains and hills

The highland regions of Israel include the historic areas of Upper and Lower Galilee, Samaria and Judaea. Upper Galilee is structurally part of the Mountains of Lebanon - a limestone plateau dominated by Mount Hermon (2814m). Lower Galilee, to the south, is broken into many smaller hills of lower altitude and shallower gradient.

The hills of Samaria are situated between the Valley of Jezreel and Judaea. Samaria is lower in elevation than Galilee or Judaea, and has an undulating topography. The boundary between Samaria and Judaea is not physically well defined, but may be thought of as passing some 15km north of Jerusalem (Karmon, 1971). Unlike Samaria, Judaea is a high plateau region that varies in height from 450m to 900m. The Judaean landscape is bleak and rocky.

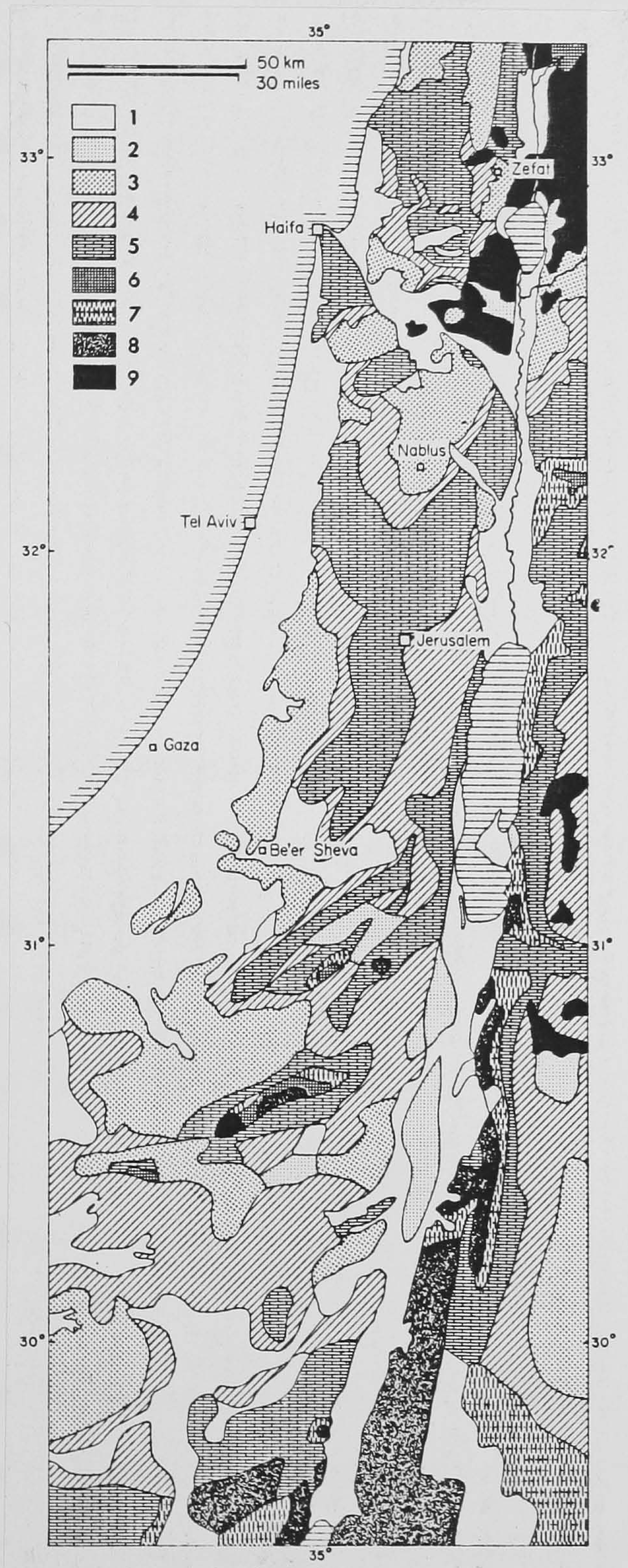
8.3.3 The Jordan rift valley

The Jordan rift valley extends the entire length of Israel, from the Gulf of Aqaba in the south to the Lebanese border in the north. It varies in width from 3km to 25km, and its lowest point is in the Dead Sea depression at 396m below sea level. The rift forms a single structural unit bounded by steep faulted sides, but can nevertheless be subdivided into several sub-regions. In the north lies the Hula basin. One third of this was formerly occupied by a shallow lake (Lake Hula), where papyrus and other reeds formed malarial swamps. It is now an area of fertile agriculture, having been drained by the Jewish Foundation between 1951 and 1957.

South of the Hula basin lies Lake Tiberias (Lake Kinneret) which is Israel's largest freshwater lake. It is situated 210m below sea level. To the south of Lake Tiberias, the River Jordan meanders 100km to the Dead Sea through the Ghor region. Until recently the floodplain of the Jordan was covered by thick swamp vegetation, caused by river flooding. Much has now been done to alleviate the flooding problem, and the swamp has been cleared. Although rainfall is generally less than 300mm, irrigation now sustains successful

Figure 8.3

The surficial geology of Israel



KEY

1. Quaternary (alluvium, sand, loess)
2. Neogene (terrestrial and lacustrine deposits)
3. Lower Tertiary (Eocene, Oligocene: chalk, marl, limestone)
4. Senonian (soft limestone, marl, chalk)
5. Cenomanian-Turonian (dolomites, limestone, marl)
6. Jurassic-Triassic (mainly limestone)
7. Nubian Sandstone
8. Precambrian
9. Volcanic material (basalt)

After Karmon (1971, p.8)

agriculture in parts of the Jordan valley.

The Dead Sea region (and the Arava depression further to the south) have never been important for settlement, though some experimental kibbutzim have been established. The chief economic importance of the Dead Sea is its vast mineral wealth, as well as its importance as a centre for tourism.

8.3.4 The Negev

"Negev" means "dryland". The Negev is a large triangular-shaped desert that covers southern Israel. Due to low rainfall, the only possibility for extensive agricultural settlement in the Negev is in the north-west of the region, adjacent to the Gaza strip. Water is piped here from Lake Tiberias for irrigation purposes. The Negev hills, in the central and south-western part of the desert, are almost completely uninhabited.

8.4 SURFICIAL GEOLOGY

In Section 7.7, it was shown that the R.O.A. zonation scheme includes a consideration of the effects of surficial geology in controlling the severity of earthquake hazard. As far as Israel is concerned, the geology is relatively young and uncomplicated, with little surface variation. Figure 8.3 shows the distribution of the major lithological units in the region.

8.4.1 Pre-Quaternary

The Pre-Cambrian basement of Israel consists predominantly of metamorphosed sequences. These outcrop to the west of the rift valley, at the north-western extremity of the Gulf of Eilat. Crystalline basement also outcrops to the east of the southern part of the rift valley, in The Jordan.

The reason for the restricted exposure of basement rock in Israel, is that most of the old rock units are buried beneath more recent marine sedimentary formations. These form three-quarters of all the rocks that outcrop at the surface in Israel (Horowitz, 1979). Some of the oldest exposed sedimentary strata belong to the Nubian sandstone formation (Palaeozoic-Mesozoic age). On the western side of the rift valley, Nubian sandstone outcrops in the northern Negev. It also outcrops along the faults and eastern cliffs of the Jordan-Arava graben, and deep inside the Edom and Midian regions of The Jordan. There are no significant outcrops of Nubian sandstone in central and northern Israel.

Marine sediments of the Mesozoic period form the main sedimentary sequences that outcrop at the surface in Israel. These consist predominantly of limestones and dolomites of varying consistency and hardness, intercalated with different types of marl. In the hills of northern and central Israel, and throughout substantial parts of the Negev, the most important Mesozoic strata are hard grey dolomitic limestones of Cenomanian-Turonian (Cretaceous) age. Across large parts of Israel, these strata are postdated by carbonate rocks of Eocene-Senonian age. The Eocene-Senonian carbonates consist predominantly of soft limestones or chalk, interbedded with layers of marl.

8.4.2 Quaternary

Faulting, accompanied by strong lateral and vertical movements, has resulted in the formation of the Jordan rift valley. This is the deepest inland depression on Earth, and contains the Jordan valley, the Dead Sea depression (396m below the level of the Mediterranean Sea), the Arava depression and the Gulf of Aqaba. Minor transverse faults have created a number of smaller depressions, of which the largest is the Valley of Jezreel in the north (see Figure 8.2). Volcanic activity associated with the tectonic movements produced the basalt lavas and tuffs that outcrop in northern Israel. The extrusives are of Upper Tertiary to Pleistocene age, and cover extensive elevated plateaux throughout the Golan region. They extend west of the rift into eastern Galilee and the Valley of Jezreel.

The Jordan rift valley is a region of rapid sedimentation, with single formations achieving great thicknesses. The main sedimentary sequence in the rift valley is of Pleistocene age. It was deposited at a time when the whole of the central part of the valley was covered by a brackish-water lake. According to Ben-Arieh (1964), this lake stretched from the northern end of (present day) Lake Tiberias, to the vicinity of Hazeva (30km south of the Dead Sea). The former extent of the lake is now marked by the occurrence of Lisan marl, a soft and extremely friable rock consisting of alternating laminae of marl and gypsum/calcite. The exposed strata are impermeable and have been subject to severe erosion to form "badland". To the north of Lake Tiberias, thick peat deposits have accumulated in the Hula depression.

Like the rift valley, much of the evolution of the coastal plain of Israel took place during the Pleistocene. The dominant features of the plain are parallel ridges of calcareous sandstones (kurkar) and sand dunes. The north-south alignment of these units is thought to be related to alternating regressions and transgressions of the Mediterranean Sea during the Pleistocene.

Kurkar is sandstone that has been cemented with the aid of calcareous solutions (Avnimelech, 1960). Kurkar ridges are solidified sand dunes. The ridges reach heights of up to 100m, but are often buried beneath a cover of more recent dune sand. They are best developed in the Sharon (central part of the coast), where there are 3 parallel ridges each of which is 300m-500m wide. The ridges are from 1km to 3km apart, and are almost continuous; they are broken only where the rivers of the Sharon cut through them.

The kurkar ridges form the western margin of the coastal plain. The central part is largely covered by dune sand, but also contains some swampy areas. The eastern margin consists mainly of flat alluvial deposits.

Extensive sandy areas are also found far from the coast, in the Negev hills. Characteristic alluvial deposits in these hills include sandy silts, silts mixed with pebbles, playa silts and alluvial fan deposits.

8.5 APPLYING THE R.O.A. HAZARD ZONATION SCHEME TO ISRAEL

Since the foundation of the Jewish State in 1948, Israel has not experienced a major earthquake event. However, this fact should not be taken to minimise the threat posed by earthquakes to large parts of the country. As was highlighted in Chapter 6, the past 40 years is a negligibly short time period on which to base loss experience and hazard/risk evaluations. Evidence derived from the historical catalogue (Appendix A) clearly shows that many of the major cities in Israel have repeatedly experienced earthquake damage (see Figure 5.4).

On the basis of analysis of regional tectonics and 20th century seismicity (Chapter 4), and historical earthquake data (Chapter 5), it was concluded (in Chapters 5 and 6) that Israel is vulnerable to earthquakes generated in two major tectonic zones:

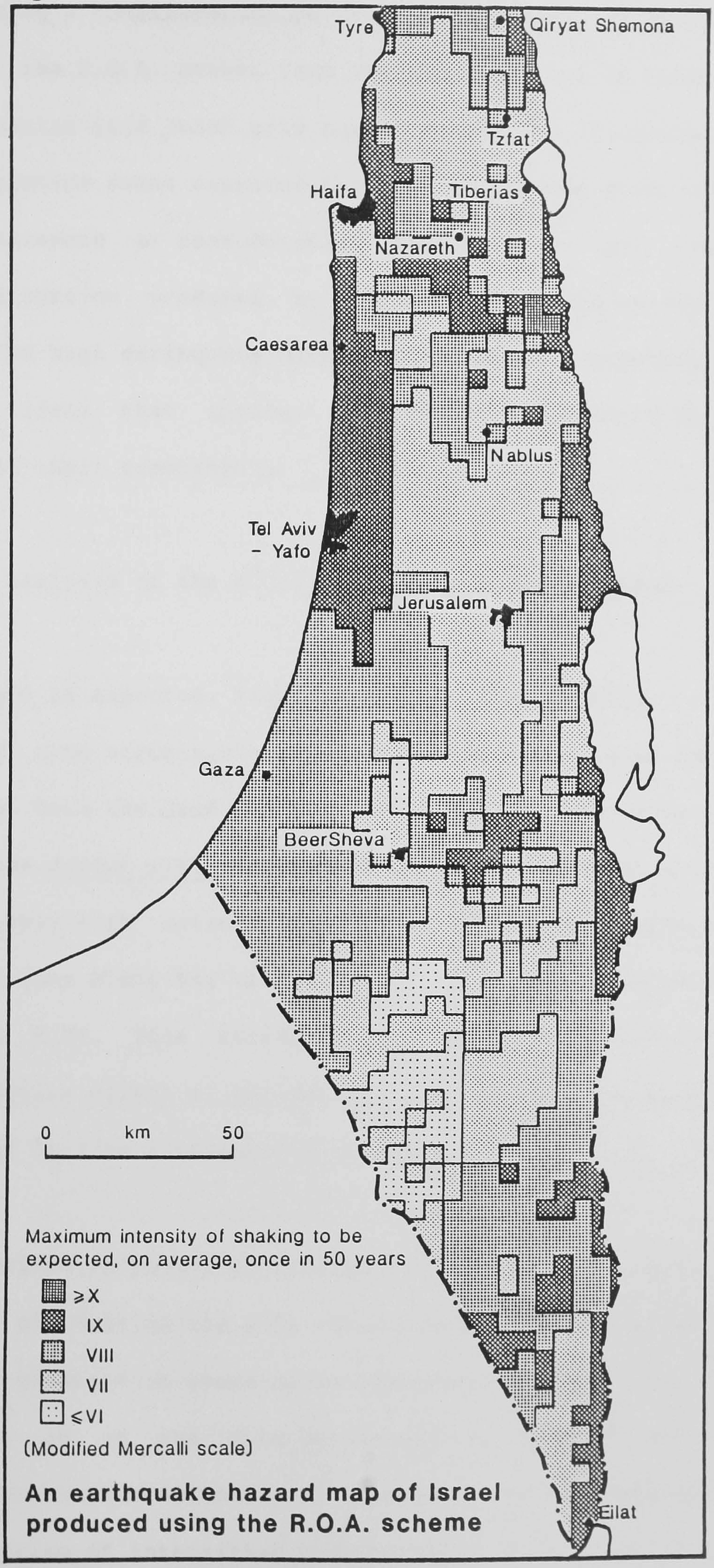
a) the eastern Mediterranean basin;

b) the Jordan rift valley.

The earthquake hazard zonation of Israel produced by the Munich Re. (1978) reflects this pattern of earthquake activity. It divides the country into two exposure zones (see Figure 7.1). The zone of greatest hazard (intensity =VIII) includes much of eastern, central and northern Israel. South-western Israel is shown as expecting a maximum intensity of VI-VII, once every 50 years (on average). The relative simplicity of the zonation, reflects the fact that it does not take into consideration the effects of surficial geology in controlling the severity of earthquake hazard (i.e. it provides an assessment for average ground conditions - see Section 7.5.2).

Figure 8.4 is an attempt to refine the Munich Re. zonation, by

Figure 8.4



An earthquake hazard map of Israel produced using the R.O.A. scheme

including a consideration of ground conditions. It has been produced using the R.O.A. scheme (see Section 7.7), and is based upon a 5 by 5 kilometre grid (each grid square represents 25 square kilometres). The zonation shows expected intensities ranging from <=VI to >=X. It is therefore a considerable improvement upon the two-part classification produced by the Munich Re., and serves to delineate areas of high earthquake hazard with greater accuracy. It is in these areas that insurers and reinsurers need to be particularly wary of their commitments.

8.5.1 Analysis of the R.O.A. hazard zonation of Israel

As might be expected, Figure 8.4 shows that a major zone of high hazard runs north-south along the eastern margin of Israel, passing through both the Dead Sea and Lake Tiberias. This zone is associated with the Jordan rift valley, and is attributable to a combination of relatively high seismic activity, and very unstable geological foundations along the valley floor (i.e. a thick alluvial fill - see Figure 8.3). This alluvial fill has often served to increase the destructive effect of earthquakes (e.g. those that have affected the city of Jericho throughout history).

The maximum intensity of ground shaking to be expected along the floor of most of the rift valley is IX. The hazard is likely to be at its greatest in those areas where the valley is, or was formerly marshy, as in the Hula depression to the north of Lake Tiberias. Here the maximum intensity of shaking to be expected may be >=X. The distinction of intensities greater than X is pointless. This is because the added threat posed by intensity XI or XII, compared to that of X, is of little significance. According to Richter (1959), distinction of intensities greater than IX is not easy, even with good data. Figure 8.4 shows that very few parts of Israel may be expected to experience intensity X once in 50 years.

The zone of high hazard associated with the rift valley is restricted in lateral extent. This is mainly because earthquake shock waves originating along the rift do not seem to propagate very far away from it in an east-west direction (see Section 5.5.2.2 and Figure 5.6). Their effects are principally confined to the rift valley and its immediate vicinity.

A second major zone of high earthquake hazard follows the <u>Mediterranean coastline</u> of Israel. The hazard is greatest along:

- a central section of the coastal plain, that runs north from Yavne through the Tel Aviv metropolitan area to Atlit;

- a northern section, that runs from Haifa Bay across the Valley of Zevulun to just beyond Nahariyya.

In both areas the maximum intensity of shaking to be expected is IX. Along the southern coastal plain of Israel, the hazard is reduced slightly in relation to the aforementioned areas, and a maximum intensity of VIII is to be expected.

The high hazard status of the coastal region is attributable to the combined effects of proximity to an active tectonic zone, and the unstable foundations provided by unconsolidated deposits of the coastal plain (predominantly alluvium and sand - see Figure 8.3). Large parts of the coastal region consist of reclaimed marsh (see Section 8.3.1), and it is in these areas that the hazard is greatest.

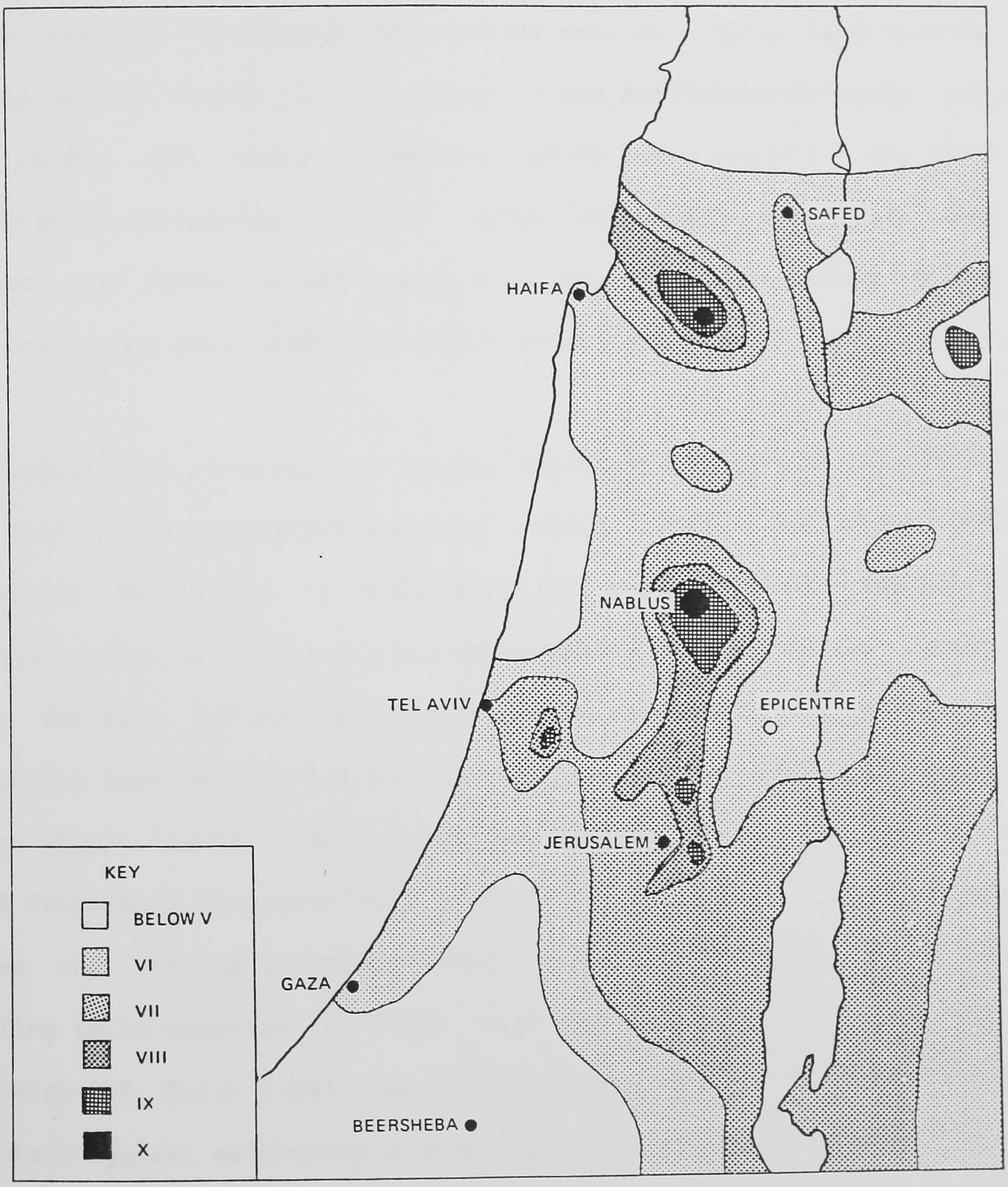
The offshore tectonic zones of the eastern Mediterranean basin pose a particular threat to the Israeli coastal region. As was highlighted in Chapters 4, 5 and 6, the zones are associated with the occurrence of large magnitude intermediate-depth earthquakes. These have caused severe damage in the coastal cities of the Levant in the past. The most active offshore zone lies between the Lebanese coast and Cyprus, so that it is in the northen and central coastal plains of Israel that the hazard is greatest. The hazard is reduced slightly in the southern coastal plain.

In addition to the threat posed by distant offshore faulting, there are numerous onshore and nearshore faults in the coastal region of Israel. The potential of these faults to generate destructive earthquakes is still not fully understood. There has been little seismic activity in the coastal region this century. However, Neev et al. (1973) have provided evidence of Recent faulting along the Mediterranean coast of Israel, based on various archaeological and geological observations. Horowitz (1979) concluded that tectonic movements do affect the Israeli coast at present, but suggests that on average they are not capable of causing strong ground disturbances.

A third zone of relatively high earthquake hazard follows the Valley of Jezreel (maximum intensity =VIII-IX). Once again, there is little

Figure 8.5

Sieberg's (1932) isoseismals for the Palestinian earthquake of July 11, 1927



After R.O.A (1976, p.28)

evidence to suggest that this area in itself is particularly seismically active, though the southern margin of the valley is bounded by the Carmel fault. The high hazard status of the Jezreel region is mainly attributable to the presence of thick alluvial deposits in the valley bottom (much of which was formerly marshy). These unstable geological foundations make the valley sensitive to ground motions caused by earthquakes in the Mediterranean basin and the Jordan rift valley. Sieberg's (1932) isoseismals for the 1927 Palestinian earthquake (the last major earthquake to affect the region - see Table 3.6 and Figure 4.1), show that the Jezreel valley was one of the worst affected areas (see Figure 8.5).

Throughout the remainder of Israel, earthquake hazard is reduced in relation to the aforementioned high hazard areas. The amount of reduction in hazard is controlled by distance from the major tectonic zones (i.e. the eastern Mediterranean basin and the Jordan rift valley), and by the firmness of the substratum. The hazard is generally much less severe along the north-south trending <u>highland axis</u> of the country, where the underlying geology is principally of hard Cretaceous limestone or dolomite (see Figure 8.3). Figure 8.4 shows that in the limestone areas, the maximum intensity of ground shaking to be expected is VII. This is in agreement with the findings of Arieh (1967). He concluded that in the majority of the highland region, earthquake ground shaking "may hardly exceed a 7th degree intensity vibration even in the case of major seismic events (M>=6) as demonstrated e.g. by the minor damages in Jerusalem during its long recorded seismic history" (p.13).

The highland region does contain some areas of relatively high earthquake hazard, where intensity VIII and occasionally IX can be expected (e.g. in parts of the Galilean hills). These zones of increased hazard are usually associated either with:

a) areas underlain by bedrock that is softer than the limestone (e.g. chalk or marl);

b) alluvial fills in valleys.

Earthquake hazard in Israel is least in the central southern part of the country (intensity <=VI). This is due to the greater distance of this area from the active faults of the Mediterranean basin and Jordan rift valley, and to the presence of hard limestone rock as a foundation across much of the region.

It was not felt necessary to distinguish between intensities of less than VI on the hazard map. Structures that have been reasonably constructed should not show any but the most minor damage when subjected to intensity VI (Richter, 1959). The Munich Re. (1976) have shown that significant loss in buildings does not occur until intensity VI-VII has been reached.

8.5.2 Testing the validity of the R.O.A. hazard zonation of Israel

It is extremely difficult to test the validity of Figure 8.4. This is because the zonation attempts to predict future earthquake effects. The true value of it will therefore only be brought to light through close monitoring of the earthquakes experienced in Israel during the years to come.

TABLE 8.1

Relating the Historical Earthquake Record of Israel
to the R.O.A. Earthquake Hazard Zonation of the Country

Intensity Zone (from the R.O.A. Hazard Zonation)	% Area of Hazard Zonation Assigned to Each Intensity Zone	Number of Settlements Experiencing Historical Earthquake Damage in Each Zone (%'s of Total in Brackets)	Average Number of Times the Damaged Settlements in Each Zone Have Been Affected by Earthquakes*
>=X	0.5	0 (0%)	-
IX	17	18 (45%)	3.3
VIII	42	14 (35%)	3
VII	36	8 (20%)	1.3
<=VI	4.5	0 (0%)	-

*excluding Jerusalem from the analysis

Source of data: Figure 8.4 and Appendix A (an analysis of the records of earthquake damage in Israel)

Nevertheless, some attempt must be made to assess the accuracy of Figure 8.4, if the R.O.A. zonation scheme is to be accepted as a credible zoning technique. The only valid means available at present to test the zonation, is to relate it to the record of historical earthquake activity in the country (documented in Appendix A). To some extent this argument is a circular one, in that the zonation itself is partly based upon an analysis of historical data, as incorporated in the hazard zonation produced by the Munich Re. These data, however, form only part of the zonation process, and equal emphasis is placed by the R.O.A. scheme upon the role of surficial geology in controlling the severity of the hazard. The zonation is therefore not entirely dependent upon the record of historical seismicity.

It should also be borne in mind that the historical data listed in Appendix A are probably more comprehensive than those used by the Munich Re. to produce their zonation. The data therefore provide an ideal means of testing the concept that the Munich Re. zonation can be used as a base map from which accurate hazard zonations can be derived.

Table 8.1 presents the results of a detailed analysis of the records in the historical catalogue that refer to Israel; there are 152 entries concerning the country (see Appendix A2). These list a total of 43 different settlements that have been affected by earthquakes. Of these, 40 have been located in relation to the hazard exposure zones shown on Figure 8.4. The table shows that almost half (45%) of the 40 settlements are located in exposure zones with an expected intensity of IX. This is despite the fact that these zones cover only 17% of the hazard map. Together, intensity zones VIII and IX cover only 59% of the zonation, but contain 80% of the settlements historically affected by earthquakes. In contrast, intensity zone VII covers 36% of the hazard map, but only 20% of the affected settlements are located within it. There are no records of damaged settlements in intensity zones VI and X. In the case of X, this is undoubtedly due to the very limited number of exposure zones in which this intensity is expected, and to the absence of any permanent settlements from these (which makes an historical record unlikely, even though strong earthquake ground motions may have been experienced).

Table 8.1 also shows that the frequency of damaging earthquakes has been greater in intensity zones VIII and IX, than in zone VII. Each affected settlement in zone IX has, on average, 3.3 entries referring to it in the catalogue. The average number of entries for the affected settlements in zone VII is only 1.3. Jerusalem was excluded from the analysis because of the disproportionately large number of earthquake records for the city (explanations for this are given in Sections 5.3.1 and 8.7.7).

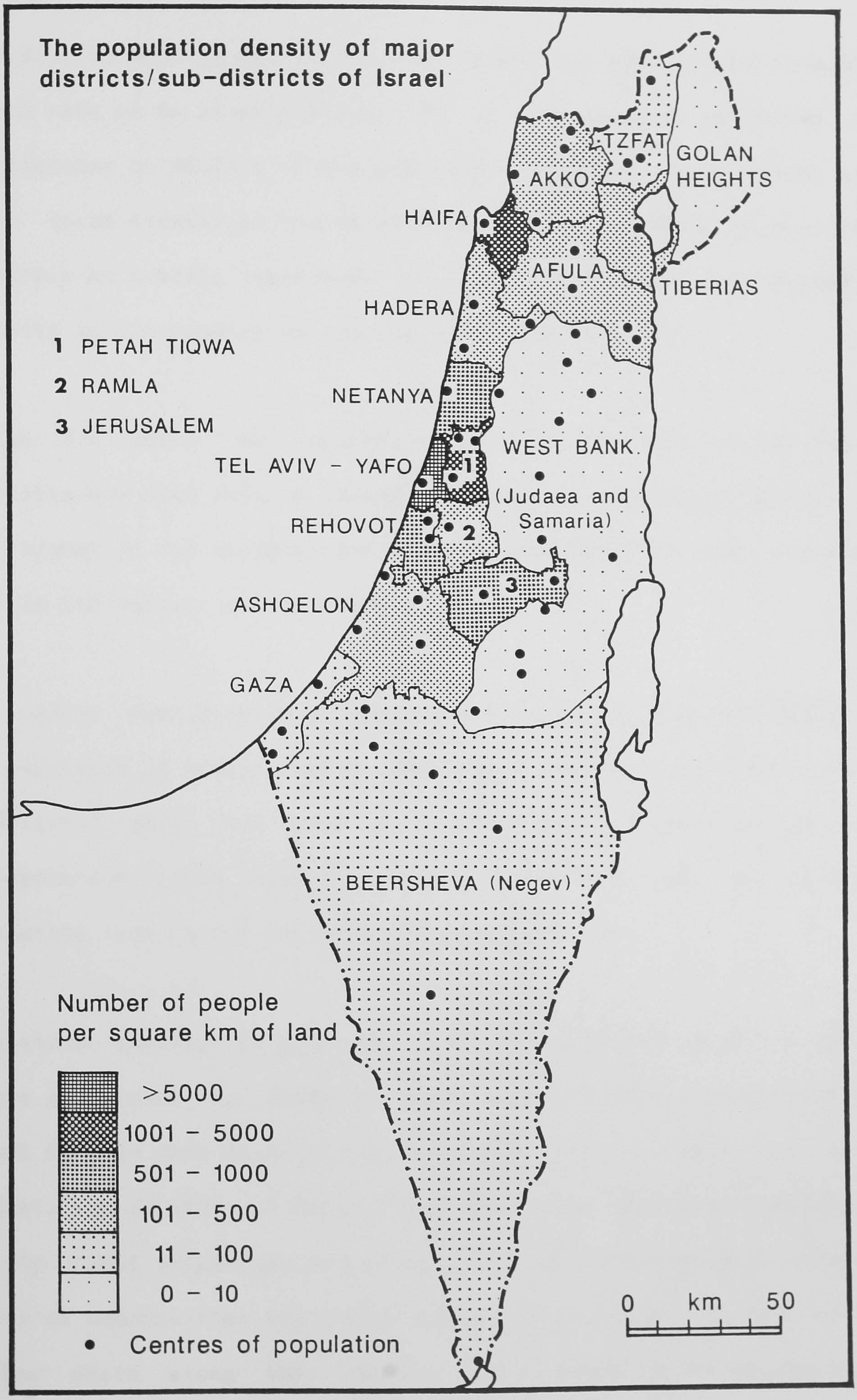
The greater incidence and frequency of historical earthquake damage in the zones of highest hazard on Figure 8.4, would seem to suggest that it gives a reliable impression of the distribution of earthquake hazard in Israel. The zonation clearly serves to delineate the areas of greatest hazard with considerable accuracy.

In order to test the zonation more fully, it would be necessary to include a consideration of population density in the analysis presented in Table 8.1. This, however, is extremely difficult to do, simply because of a lack of reliable historical data. At the present time, many of the largest Israeli settlements are located in the coastal region, which is one of the most hazardous parts of the country (this is something that will be discussed in greater detail in the next section). Historically, however, the coastal plains probably contained fewer large settlements than the highland areas of Israel. This is because up until Jewish colonisation in the 20th century, many of the plains were covered with malarial swamps (see Section 8.3.1). Historical population densities were, therefore, probably greatest in the highland areas, most of which have been assigned to intensity zone VII on Figure 8.4. This would seem to indicate that the reduced number of historical earthquake reports from zone VII cannot be explained away in terms of lower historical population densities than in zones VIII and IX. It reinforces the conclusion that the impression of earthquake hazard distribution given by Figure 8.4 is an accurate one, and that the R.O.A. scheme can be used to derive credible hazard zonations.

8.6 USING THE R.O.A. HAZARD ZONATION TO IDENTIFY AREAS OF HIGH EARTHQUAKE RISK IN ISRAEL

As discussed in Section 7.2.3, an earthquake hazard zonation map is a primary requirement in the delineation of earthquake risk (i.e. the loss that can be expected due to earthquakes). By relating such a map to a map showing the distribution of population/economic activity in a country, it is possible to highlight those areas where human or economic earthquake losses are likely to be greatest.

Figure 8.6



Source of data: Central Bureau of Statistics (1982, p.36)

8.6.1 Centres of population and economic activity in Israel

According to Bolt et al. (1975), "in industrial nations the economic growth rate of an urban district will in many cases be reflected by the increase or decline of the population" (p.292). Since Israel is, to a large extent, an industrialised nation, it should be possible to obtain an overall impression of the distribution of economic activity in the country by mapping population density.

Figure 8.6 shows the population density of each of the major districts/sub-districts of Israel. In general, population density is much higher in the northern and western districts of the country, than in the eastern and southern.

The narrow 90km stretch of coastline between Tel Aviv and Haifa is the heartland of modern Israel. Many early Zionist settlements were established here, and today it contains the densest concentrations of population in the country. Nearly two-thirds of the Israeli population live in Tel Aviv and the central coast.

Population density is greatest in the Tel Aviv-Yafo district (5906 people per square km). Table 8.2 shows that 25% of the population of Israel live in this district. To the east of Tel Aviv and Yafo (Jaffa), the district of Petah Tiqwa also has a very high population density (1011 people per square km). This district contains a large number of suburbs that are within commuting distance of Tel Aviv. Further north along the coastal plain, Haifa is the second most densely populated district in Israel (1,436 people per square km). This district accommodates 14% of the total population of Israel.

TABLE 8.2

Percentage of Total Population Living in Particular Districts and Sub-Districts of Israel

District or Sub-District*	% of Population
JERUSALEM District	11.5
NORTHERN District	15.8
Tzfat Sub-District	1.7
Kinneret Sub-District	1.6
Jezreel Sub-District	5.8
Akko Sub-District	6.7
HAIFA District	14.3
CENTRAL District	20.3
Sharon Sub-District	4.7
Petah Tiqwa Sub-District	7.2
Ramla Sub-District	2.8
Rehovot Sub-District	5.6
TEL AVIV District	25.2
SOUTHERN District	12.2
Ashqelon Sub-District	5.1
BeerSheva Sub-District	7.1
Judaea and Samaria (West Bank)	0.4
Gaza and Sinai	0.1
The Golan	0.1

* See Figure 8.6

Source of data: Central Bureau of Statistics (1982; p.33)

The Jerusalem district (729 people per square kilometre) has a much lower population density than many of the coastal districts. However, with a total population of 415,000, the city of Jerusalem itself has a greater number of inhabitants than any other single Israeli city. Further to the north, the Galilean districts have moderate population densities that range from approximately 100 people per square kilometre in Tzfat, to 287 people per square kilometre in Akko and Hadera districts. Similarly, Ashqelon district, in the southern coastal plain, has a moderate population density of 160 people per square kilometre.

The lowest population densities in Israel are in those regions which have recently been annexed by the State. The Golan district, for instance, has a population density of 5 people per square kilometre. The West Bank has 3 people per square kilometre. 0.1% and 0.4% of the Israeli population live in the Golan and West Bank districts respectively.

Population density in the Gaza strip is also low (11 people per square km). Again, only 0.1% of the population of Israel live in the Gaza strip. To the east of Gaza, the population density of the Negev region is only 22 per square kilometre. Surprisingly enough, the Negev district accommodates 7% of the Israeli population, though the vast majority of the inhabitants live in the regional capital, BeerSheva (population 111,200).

8.6.2 Identifying areas of relative earthquake risk in Israel

By comparing the R.O.A. earthquake hazard zonation of Israel (Figure

8.4) with the map of population density (Figure 8.6), it is possible to obtain a general impression of the distribution of earthquake risk in the country.

Earthquake risk is relatively high in the coastal belt of Israel. Here, a combination of high hazard status and dense concentrations of population give great potential for large earthquake loss accumulations. The Tel Aviv metropolitan area and the district of Haifa are of particular concern because of their very high population densities.

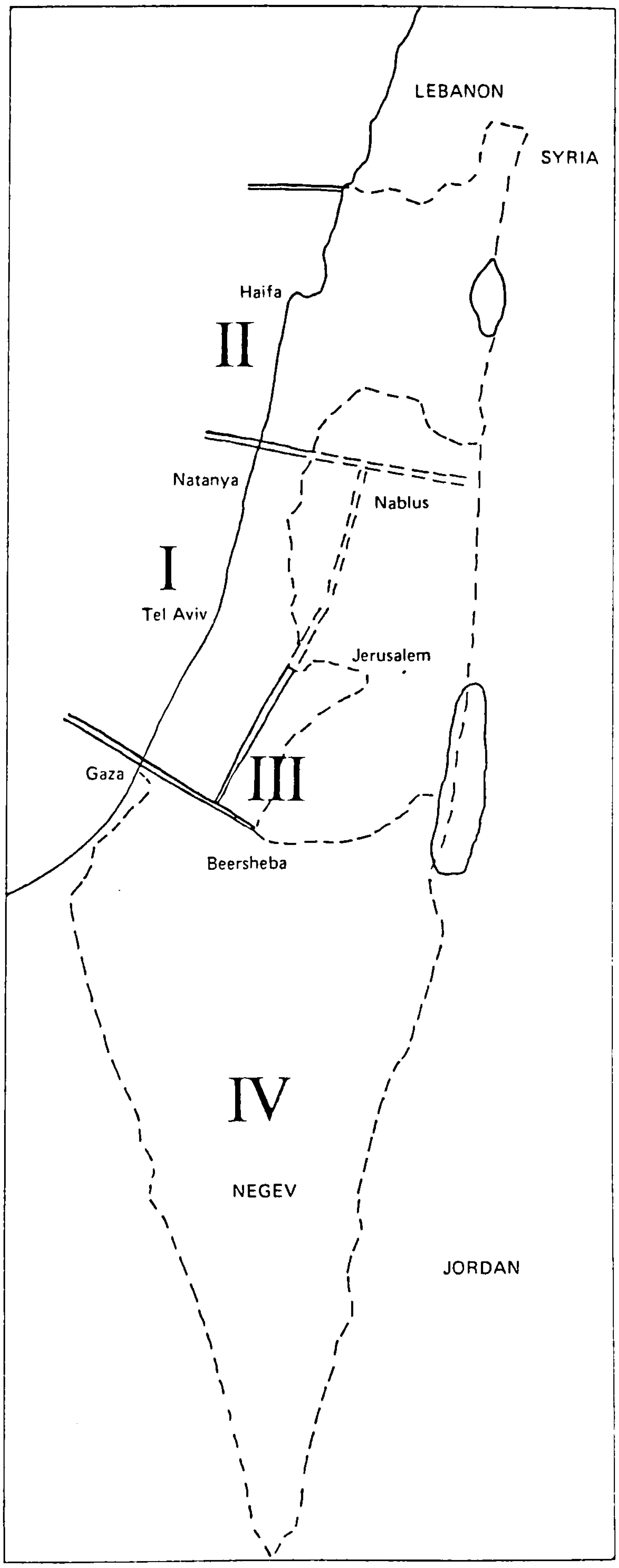
In contrast, although the Jordan rift valley and Jezreel valley are areas of high earthquake hazard, the potential for very large losses in these areas is reduced due to the fact that they are much less densely populated. However, certain isolated centres of population are of concern (e.g. Tiberias, Eilat and Qiryat Shemona).

Earthquake risk is low over much of the highland region of Israel. This is because the region is sparsely populated and has a relatively low hazard status. However, some centres of population do occur in areas of relatively high hazard (e.g. Tzfat, Nazareth and Nablus).

Earthquake risk is least in the central southern part of Israel. This is due to a combination of very low population densities and low hazard status. The largest centre of population in the region is BeerSheva, but Figure 8.4 shows that earthquake hazard in the vicinity of the city is not particularly great.

Figure 8.7

The R.O.A. accumulation assessment zonation of Israel



After R.O.A. (1976, p.30)

8.6.3 Insurance zonations for assessing earthquake risk in Israel

In 1976, the Reinsurance Offices Association produced a zonation of Israel for use by insurance underwriters in appraising their probable maximum earthquake losses (see Figure 8.7). The zonation serves to distinguish between broad zones of earthquake risk in the country, but needs refinement. This is particularly the case for the coastal region, where major centres of population occur.

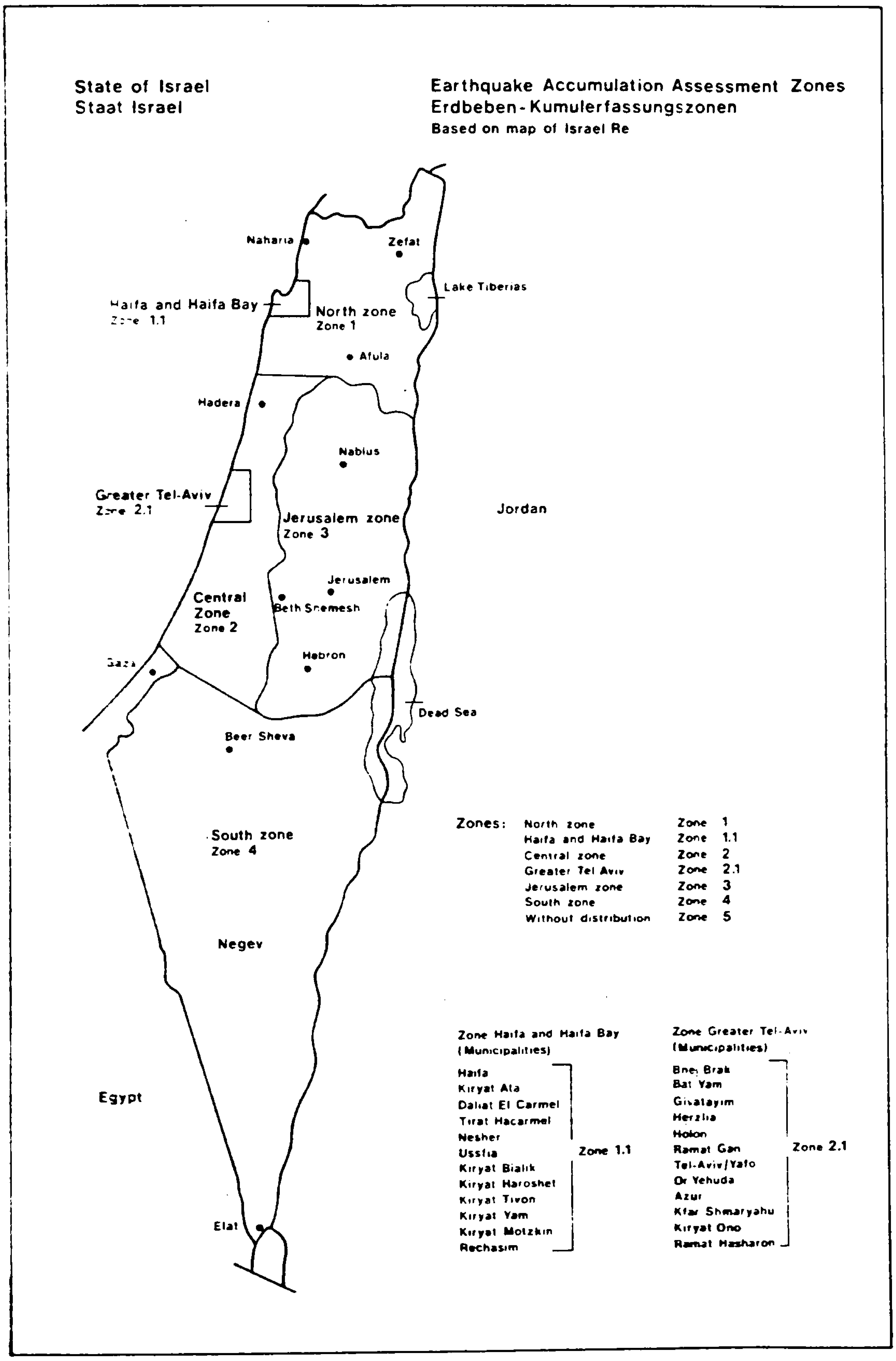
An improved zonation is the map of accumulation assessment zones produced by CRESTA (a body dedicated to the standardisation of catastrophe risk evaluations). The CRESTA zonation (see Figure 8.8) recognises Haifa and Greater Tel Aviv as areas of particularly high earthquake risk, and assigns them separate accumulation assessment zones within the coastal region. This serves to emphasise the great care that insurers and reinsurers need to take in the assessment of earthquake hazard, and control of earthquake risk, within these areas of high population density and intense economic activity. Aspects of earthquake risk accumulation assessment and control will be discussed in greater detail in Chapter 9.

8.7 EARTHQUAKE HAZARD IN MAJOR ISRAELI CITIES

Figure 8.4 is intended to provide insurers and reinsurers with a general impression of the distribution of earthquake hazard in Israel. Although it is obviously a major improvement upon the map produced by the Munich Re. (see Figure 7.1), it still has several major short-comings. Most important of these is the size of the grid square used in the compilation of the map (5km x 5km).

Figure 8.8

The CRESTA accumulation assessment zonation of Israel



After CRESTA (1987)

As explained in Section 7.8, in order to produce the map it was necessary to assign one lithology type to each grid square. In areas of variable surficial geology, the dominant lithology in each grid unit was adopted. Such an approach obviously reduces the accuracy of the final zonation that is produced, but has to its advantage the fact that it serves to distinguish areas of different hazard potential much more clearly than does the map published by the Munich Re. Figure 8.4 should therefore be used only to obtain a general impression of the exposure of Israeli cities to earthquake hazard. It is to be hoped that no-one will go to the length of using the map to assign different hazard values to adjacent towns (situated on the same type of ground), simply because a grid-line passes between them on Figure 8.4. More precise studies need to be carried out to accurately define the hazard within major Israeli cities.

In the following section, earthquake hazard in a number of major population centres in Israel is discussed in greater detail. Attention is focussed upon those factors which serve to increase or decrease the severity of earthquake hazard in these areas. In addition, large-scale zonation maps are provided for two of the cities (Haifa and Tiberias), in an attempt to show how the hazard zonation process can be taken a stage further from that presented in Figure 8.4.

The cities chosen for analysis are those for which the relevant data are available, or at which site examinations have been conducted during the present study. They are intended to provide as complete a sample coverage of the country and its different regional environments (and geological settings) as is possible (see Sections 8.3 and 8.4). No other inferences should be drawn from the fact that a city or town is included or excluded from the analysis.

8.7.1 THE TEL AVIV-YAFO METROPOLITAN AREA

Tel Aviv (population 329,500) and its suburbs are the financial and industrial centre of Israel. The city was founded in 1909, and therefore does not feature in the historical earthquake catalogue (Chapter 5; Appendix A). The town of Yafo (Jaffa), however, is reputed to be the oldest harbour in the world. It provides considerable evidence for the occurrence of large earthquakes in the region - there are thirteen entries for Yafo in the catalogue. It is therefore imperative that earthquake hazard in this part of the Israel is zoned as accurately as possible.

Figure 8.4 shows that as a whole, the Tel Aviv-Yafo urban agglomeration (population 1,555,427) is situated in a region of potentially high earthquake hazard (intensity =IX). However, a more detailed analysis of the area shows that the severity of the hazard in the metropolitan area is not uniform, but varies slightly. The old town of Yafo, for instance, is relatively secure. It is unlikely to experience an intensity of shaking greater than VII-VIII once in 50 years. This is because most of the town stands upon an elongated kurkar sandstone ridge (see Section 8.4.2) that projects out into the sea. Parts of Tel Aviv are founded upon similar kurkar units, but the vast majority of the city is less secure than Yafo because it is situated on unconsolidated sediments. These sediments include old sand dunes, and areas of alluvium (associated with reclaimed marshland) adjacent to the River Yarqon. In the suburbs of Tel Aviv, Ramat Gan (population 119,100) is situated on kurkar, and is therefore relatively secure. Petah Tiqwa (population 121,700) is more vulnerable, as it is founded on unconsolidated sediment.

8.7.2 THE CITY OF HAIFA

a) History of development of the city

Haifa (population 227,400) is the capital of northern Israel and is one of the country's premier ports. It is a centre of heavy industry and commerce.

Figure 8.1 shows that Haifa occupies a marked promontory on the Israeli coast, formed where Mount Carmel projects out into the sea. The city is divided into 3 distinct levels: the "Lower City" with the dockside and business centre, "Hadar" with its residential and commercial centres, and "Carmel" which is mainly residential and recreational. Immediately to the north of the city lies Haifa Bay. This has formed as a result of the gradual subsidence of the Valley of Jezreel relative to Mount Carmel.

As far as surficial geology is concerned, Haifa stands upon two lithological units of quite contrasting properties. Hadar and Carmel are built upon the hard limestone rock formation of Mount Carmel (see Figure 8.3). In contrast, much of the Lower City is built on a narrow strip of flat alluvial land which runs along the foot of the mountain. It was here that the ancient city of Haifa was first founded. The land area of this part of the city has been increased slightly as a result of reclamation carried out during construction of the port.

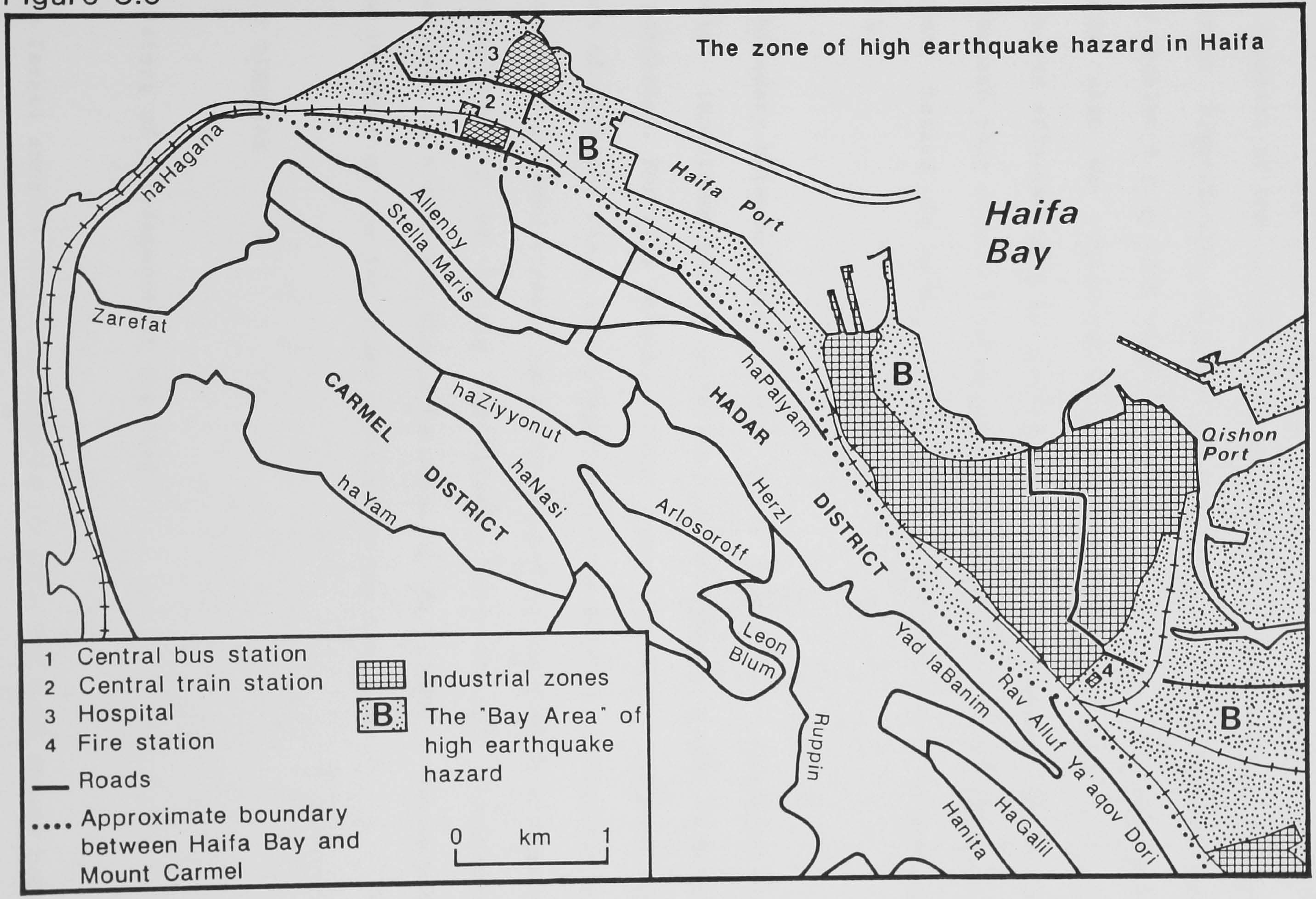
The precipitous and rocky slopes of Mount Carmel have handicapped the construction of buildings, particularly those for industrial purposes (which usually require wide flat ground). Consequently, after World War I, a broad area in the southern part of Haifa Bay (through which the River Qishon flows) was selected as the principal industrial zone for the city. This area was partly swampland, and was completely unsettled, so that it was possible to acquire cheap land and develop it for industrial purposes. The harbour and railway facilities of Haifa were built in the bay area, as were the main power station, the oil port, the refineries and the oil storage area. To the north and east of the industrial zone, the suburbs Qiryat Hayyim (population 29,700), Qiryat Motzkin (population 25,200) and Qiryat Bialik (population 29,700) were founded in 1934.

The industrial development of Haifa Bay accelerated after 1948, and a steel plant was constructed at the northern end of the bay. Today, the whole bay-side area as far north as Akko forms an almost continuous industrial zone.

b) Earthquake hazard in Haifa

Figure 8.4 shows that the maximum intensity of earthquake ground shaking to be expected in the Carmel region during the next 50 years is VII. In Haifa Bay this increases to IX or X, due to the unstable (seismically sensitive) nature of the subsoil, and the fact that much of the bay area has been artificially reclaimed. Experience

Figure 8.9



The zone of high earthquake hazard in Haifa
Haifa Bay
Haifa Port
Qishon Port
B
B
B
B
1
2
3
4
haHagana
Zarefat
Allenby
Stella Maris
haZiyyonut
haNasi
haYam
CARMEL DISTRICT
HADAR DISTRICT
haPalyam
Herzl
Arlosoroff
Leon Blum
Ruppin
Yad laBanim
Rav Alluf Ya'aqov Dori
HaGalil
Hanita
1 Central bus station
2 Central train station
3 Hospital
4 Fire station
Roads
Approximate boundary between Haifa Bay and Mount Carmel
Industrial zones
The 'Bay Area' of high earthquake hazard
0 km 1

gained from earthquakes in California and Japan, has shown that reclaimed land often responds most unfavourably to earthquake ground motions, and serves to increase the severity of earthquake impact. The deposits of the bay area are waterlogged in many places, so that sediment liquefaction could be triggered by large earthquake events (see Section 8.8.4). The threat posed by tsunamis to the bay area should also be considered. The catalogue (Appendix A1) shows that Haifa was affected by a tsunami generated by a magnitude (ML) 8.0 earthquake that occurred north-east of Crete on October 12, 1856 AD. Tsunami hazard in Israel is discussed in greater detail in Section 8.8.1.

The boundary between Haifa Bay and Mount Carmel is obviously of crucial importance as far as delineating earthquake hazard in Haifa is concerned. For this reason, it has been accurately defined by means of detailed field investigation, and is plotted on Figure 8.9. A number of named streets have been placed on the figure to enable the two zones to be easily identified. Insurers and reinsurers concerned with the city should be aware of the boundary, and should know in which of the two zones their risks are situated.

8.7.3 TIBERIAS

a) History of development of the city

Since Israel annexed the Golan Heights in 1967, the area around Lake Tiberias (Lake Kinneret) has become a popular year-round holiday spot. Tiberias (population 29,000) is the only major settlement on the lake. It is now an important tourist resort, as evidenced by the

PLATE 8.1

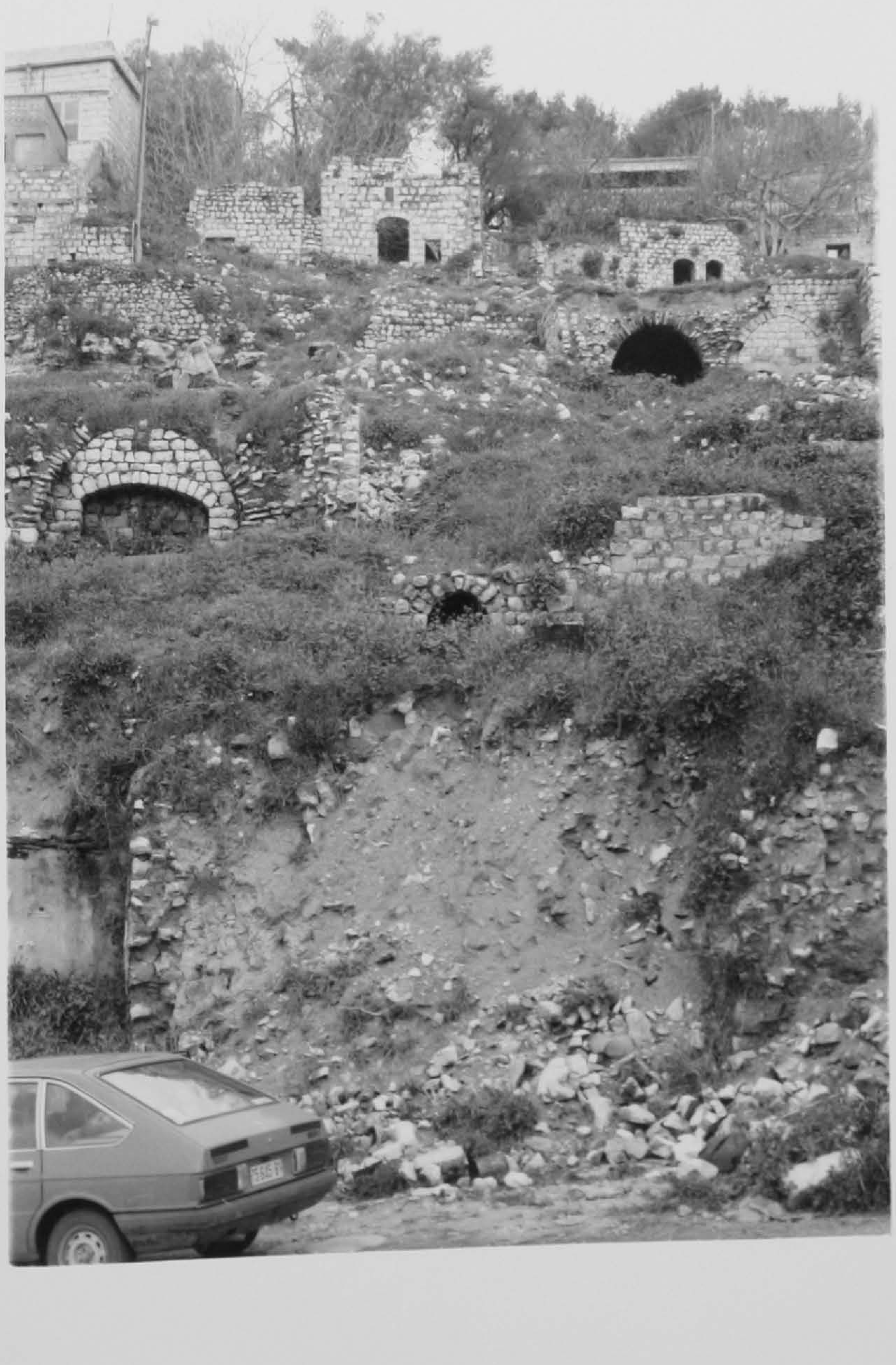
The "Old City" district of Tiberias. Note the high-rise hotels under construction along the waterfront. The photograph was taken looking in a south-easterly direction across the low-lying parts of the town towards Lake Tiberias (situated in the middle distance).

M.R.Degg (March, 1987)

PLATE 8.2

Earthquake ruins on a slope in the old district of Tzfat. The ruins date back to the 1927 earthquake.

M.R.Degg (March, 1987)



large number of modern hotels that have been constructed in the city.

The historical earthquake catalogue contains ten references to Tiberias. The city is very vulnerable to earthquakes because it lies along an active fault scarp which forms the western margin of the Jordan rift valley. Along with most of northern Israel, Tiberias was devastated by a particularly disasterous earthquake in 1837 (see Appendix A1). As a result of this and other earthquakes, very little of the old city of Tiberias survives, except for a few ruins scattered throughout the modern city.

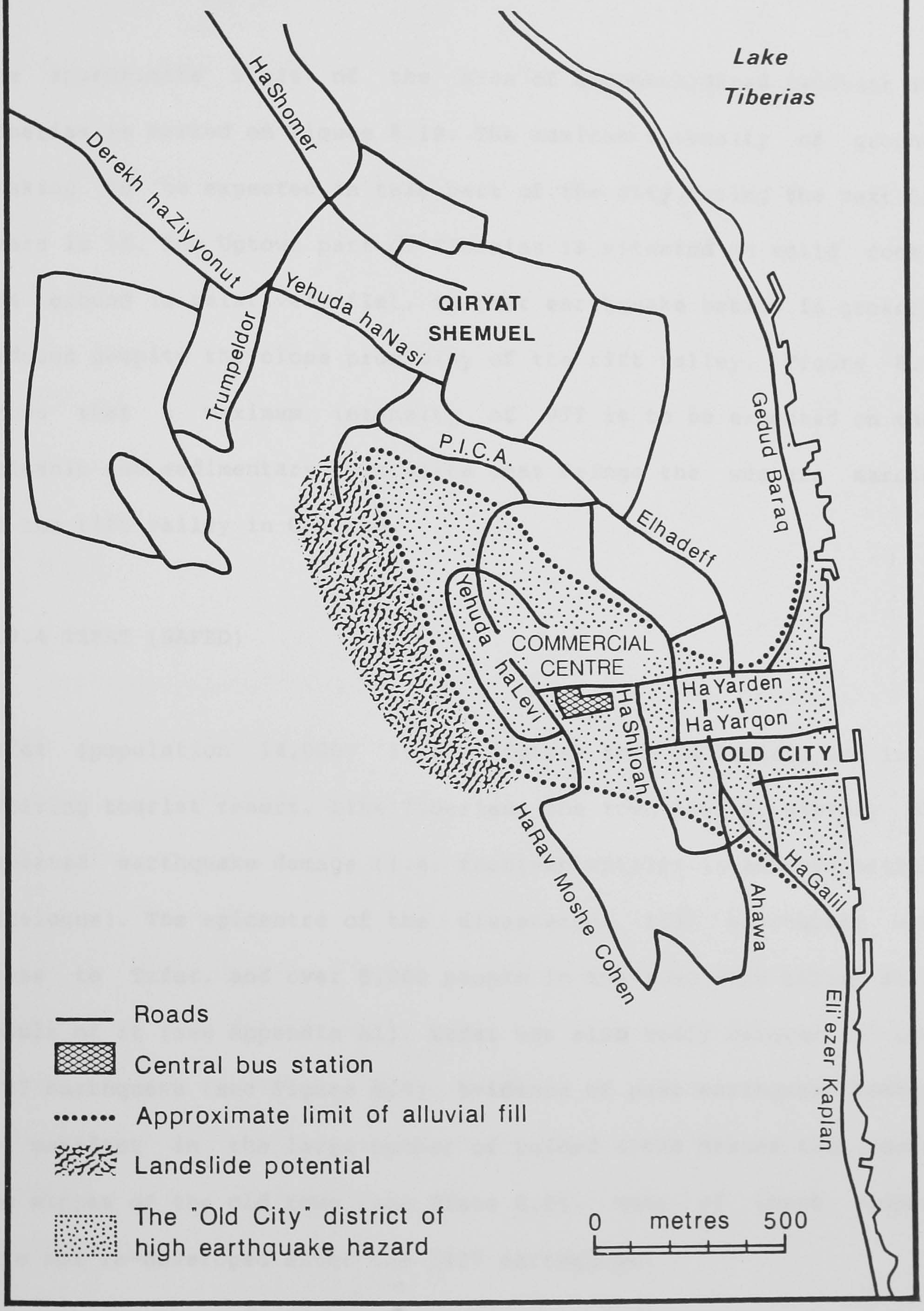
Tiberias has three levels. The "Old City" district is by the lake (see Plate 8.1), the "New City" or Qiryat Shemuel is situated along the side of the rift valley, and the "Uptown" is situated on flat land above the valley.

b) Earthquake hazard in Tiberias

The Old City district, though of small areal extent, is particularly vulnerable to earthquake ground motions because it has unstable geological foundations. These consist principally of loose sediments mixed with debris from the ruins of previous earthquakes. In addition, the water-table is probably close to the surface in this part of the city (due to the low level of the land and the proximity of Lake Tiberias), so that liquefaction could be triggered by earthquakes. Appendix A1 shows that parts of Tiberias experienced ground failure of an undefined nature during the earthquake of January 4, 1034 AD. This could possibly have included landsliding

Figure 8.10

The zone of high earthquake hazard in Tiberias



from the steep fault-scarp slope to the west of the Old City district (see Figure 8.10). There is also a danger of inundation by seismic seiches in low-lying areas of Tiberias (see Section 8.8.2).

The approximate limit of the area of unconsolidated sediment in Tiberias is marked on Figure 8.10. The maximum intensity of ground shaking to be expected in this part of the city during the next 50 years is IX. The Uptown part of Tiberias is situated on solid rock. The ground is relatively flat, so that earthquake hazard is greatly reduced despite the close proximity of the rift valley. Figure 8.4 shows that a maximum intensity of VII is to be expected on the volcanic and sedimentary rock units that fringe the western margin of the rift valley in Galilee.

8.7.4 TZFAT (SAFED)

Tzfat (population 14,000) is the highest town in Israel, and is a thriving tourist resort. Like Tiberias, the town has a history of repeated earthquake damage (i.e. fourteen entries in the historical catalogue). The epicentre of the disasterous 1837 earthquake was close to Tzfat, and over 5,000 people in the town were killed as a result of it (see Appendix A1). Tzfat was also badly damaged in the 1927 earthquake (see Figure 8.5). Evidence of past earthquake damage is manifest in the large number of ruined stone houses that cover the slopes of the old town (see Plate 8.2). Many of these slopes were not re-developed after the 1927 earthquake.

The substrate underlying large parts of Tzfat is marly chalk. This would, under normal circumstances, be expected to provide a relatively secure foundation for the town. The reason for Tzfat's historical vulnerability to earthquakes is the steep slopes (30-40 degrees) on which the old town was built. Due to the presence of marl in the substratum, these slopes provide very insecure foundations that are prone to landsliding during earthquakes.

The new quarters of Tzfat have been constructed on flat hill tops above the old town, and on the hard Eocene limestone of Mount Canaan (e.g. Habad Quarter). This has served to reduce the risk of future heavy earthquake damage in the town. Figure 8.4 indicates that a maximum intensity of VII-VIII can be expected in the newly developed parts of Tzfat.

8.7.5 QIRYAT SHEMONA

Qiryat Shemona (population 15,700) is situated in Upper Galilee near to the Lebanese border (see Figure 8.1). It is the administrative and transportation centre of Upper Galilee. A considerable amount of development has taken place in the town in recent years.

The fact that Qiryat Shemona is situated on solid rock serves to reduce its vulnerability to earthquakes. Figure 8.4 shows that a maximum intensity of VII is to be expected in the vicinity of the town. However, the higher, steeper parts of Qiryat Shemona are susceptible to landsliding (R.O.A., 1976), and could therefore experience greater intensities of shaking.

8.7.6 NAZARETH

Nazareth (population 44,900) is situated in the Galilean hills. On the hillside above the old Arab town, the modern Jewish township of Nazerat Illit (population 22,900) has developed.

The soft chalk foundations and relatively steep slopes on which the old town is built, serve to make it relatively vulnerable to earthquake ground shaking. It was damaged in the earthquakes of 1837 and 1927. The new township is situated on flat ground underlain by hard Eocene limestone, and is therefore more secure. It is unlikely to experience an intensity of shaking greater than VIII.

8.7.7 JERUSALEM

Since the 1967 Six Day War, all of Jerusalem (population 415,000) has been in Israeli hands. Recently, east Jerusalem was officially annexed to the State of Israel, in an attempt to reaffirm the city as the capital of Israel. Jerusalem is now the administrative centre of the country, and the seat of the national government.

Historically, there are more references to earthquakes that affected Jerusalem than to any other city in Israel. This is probably a reflection of the city's historical importance as a centre of population and learning (see Section 5.3.1). It should not be taken as an indication of greater vulnerability to earthquakes.

Jerusalem is susceptible to frequent earthquake ground shaking because of its proximity to the rift valley. However, the historical records show that earthquakes seldom cause particularly heavy damage in the city. This is because the intensities of shaking experienced are normally low, due to the hard rock substratum on which much of the city stands. Figure 8.4 gives a maximum expected intensity of VII for the greater part of Jerusalem and environs.

Slightly higher intensities of ground shaking are to be expected along some of the populated valleys close to the ancient City of Jerusalem. These not only have shallow alluvial fills, but also steep sides. The Qidron valley, in particular (to the south-east of the City), has historically experienced heavy earthquake damage. Wachs and Levitte (1984) have shown that some of the soft chalk slopes in the valleys around Jerusalem are very susceptible to earthquake-induced landsliding. They have identified a relict landslide on Mount Olives.

8.7.8 NABLUS

Nablus is the largest city on the West Bank, and an important business centre. The city is situated astride the Shomron valley.

Eleven entries in the historical catalogue refer to Nablus. Historical damage experience has shown that the parts of the town situated in the Shomron valley are usually shaken much more severely than those parts on the rocky hill slopes to the north and south. This is because the valley floor consists of waterlogged river alluvium, mixed with the rubble of former earthquake ruins. The aggravating influence that subsoil of this type has upon ground shaking has been manifest in several earthquakes, including that of

1927. The maximum intensity of ground shaking to be expected (once in 50 years) in the Shomron valley, may be as high as IX.

8.7.9 BEERSHEVA (BEERSHEBA)

BeerSheva (population 111,200) is located in the north of the Negev Desert, midway between the Mediterranean and Dead Sea (see Figure 8.1). It is the capital of the inhospitable Negev region. In 1948, when Israel took control of the region, BeerSheva was a village with less than 2,000 inhabitants. Today the city is one of Israel's largest.

Despite the fact that BeerSheva is an historic settlement, there are no references to it in the historical catalogue. The city stands on Lisan marl, but seems to be relatively secure because the marl is well consolidated, flat and dry (R.O.A., 1976). The vulnerability of the city is also reduced because it is located over 40km from the Jordan rift valley, and is hardly affected by Mediterranean earthquakes. Figure 8.4 shows that the maximum intensity of ground shaking to be expected in BeerSheva is VII.

8.7.10 EILAT

In 1948 Eilat was a small village. The annexation of Sinai to Israel in 1967 allowed the city to expand into Israel's foremost resort. During the past 10 years there has been considerable investment in the city, and dozens of luxury hotels and tourist facilities have developed along its coastline. With the return of Sinai to the Egyptians in 1982, Eilat (population 19,500) has become Israel's southern-most port, and the only Israeli city on the Red Sea.

Eilat lies within the Jordan rift valley, and is therefore vulnerable to earthquakes (there are five references to the city in the historical catalogue). Vulnerability is increased by the fact that the city does not have secure geological foundations, because it stands on unconsolidated sediments. Figure 8.4 shows that a maximum intensity of IX is to be expected in Eilat and environs.

8.8 THE NEED FOR MICROZONATIONS OF MAJOR ISRAELI CITIES

From the above discussions, it is apparent that a number of secondary hazards can serve to increase the severity of earthquake impact upon some Israeli cities (see also Section 5.7.1 for historical aspects). These hazards are triggered by earthquakes, and include:

- tsunamis;
- landslides;
- seiches;
- liquefaction.

In a small-scale hazard zonation (macrozonation), such as that produced using the R.O.A. scheme (Figure 8.4), it is not possible to consider the threat posed by each of the hazards listed above. As highlighted in Section 7.3.2, detailed information concerning indirect earthquake effects can only be shown on hazard microzonations.

The production of microzonation maps is beyond the scope of this study. However, a brief summary of the nature of earthquake-related hazards (as they exist in Israel) will be presented. It is essential that they are taken into consideration by insurers and reinsurers.

8.8.1 Tsunamis

Tsunamis are sea waves that are generated by earthquakes. As highlighted in Section 5.7.1, tsunamis that have affected Israeli coastal cities in the past have been generated by both offshore and onshore earthquakes. Vulnerability to tsunami inundation in Israel is largely controlled by the morphology of the coastal plain.

The supply of sand along the Mediterranean coastal plain of Israel diminishes from south to north. In the south, the rate of sand supply has overcome the rate of coastal subsidence. Accumulation of sand has occurred, causing the sea to regress (as proved by the inland position of ancient harbours), and forming a gentle slope suitable for the deposition of more sand. These conditions change at Yafo, where the supply of sand ceases to balance the rate of coastal subsidence (Emery and Neev, 1960). From Yafo northwards, the sea has therefore been able to abrade the shore to the base of the first kurkar ridge (see Section 8.4.2). This now forms a cliff which reaches heights of over 40m in parts of central Sharon. North of Atlit (15km south of Haifa) the kurkar cliff disappears, only to reappear again north of Akko, where the sea has reached and abraded the second kurkar ridge almost to sea-level.

As a direct consequence of their low relief, the southern and central parts of the Mediterranean coastline of Israel are particularly vulnerable to inundation by tsunamis (the catalogue shows that exposure is limited to the coastal fringe, and in exceptional cases up to 1km inland). In the north, it is of concern to note that Haifa Bay is amongst the most vulnerable areas. Tsunamis pose little threat to those sections of the Israeli coast that are protected by cliffs cut into the kurkar ridges.

The relative lack of development along the coast of Israel has meant that hitherto, tsunamis have caused little economic damage. However, with the recent development of industrial centres and holiday resorts in the coastal region, the potential for loss has increased considerably.

8.8.2 Seiches

This term is applied to waves generated by earthquakes in enclosed lake basins. The historical record contains several references to seiches that have occurred in the Dead Sea and Lake Tiberias (see Section 5.7.1). The threat from these is very localised, and restricted to low-lying areas bordering the shores of the two water bodies. The southern margin of the Dead Sea is particularly susceptible to inundation by seiches because of its low elevation. Adjacent to Lake Tiberias, the Old City district of Tiberias is at risk for similar reasons.

8.8.3 Landsliding

Earthquakes can trigger landslides on any slope that is steep and unstable. According to Verstappen (1981), landslides caused by earthquakes are seldom new failures. Instead, they tend to be reactivations of old slips that have occurred in the past. "Fossil" landslides can therefore be used to identify areas that are particularly susceptible to earthquake-induced landsliding.

As mentioned in Section 5.7.1, earthquakes along the Jordan rift valley have frequently triggered landslides in the Lisan marl formation. For example, the Jordan valley earthquake of September 2, 1973, triggered 3 landslides in the Lisan marl, despite the fact that the magnitude of the event was only 4.5. The marl covers large parts of the floor of the rift valley, and is very friable. It has been heavily dissected by wadi streams to leave steep, unstable slopes. Landslides in the marl have occasionally blocked the River Jordan causing flooding, and have caused minor road blockages.

The intercalated chalk/marl sequences of Galilee, Samaria and Judaea (see Section 8.4.1 and Figure 8.3) are also very susceptible to earthquake-induced landsliding. Indeed, landslides contributed significantly to the heavy damage that was experienced in Galilee during the 1837 and 1927 earthquakes. Wachs and Levitte (1981) have shown that even small magnitude earthquakes can trigger landslides in Galilee, especially during the winter.

8.8.4 Liquefaction

Liquefaction could serve to increase the severity of earthquake impact on some Israeli cities. It is a problem associated with areas of unconsolidated sediment (especially sand), where the water-table is close to the surface. Liquefaction potential in Israel is probably greatest along the coastal belt (e.g. Haifa Bay), and in the Jordan valley.

8.9 REDUCING THE VULNERABILITY OF ISRAELI CITIES TO EARTHQUAKES

Having examined in detail the distribution of earthquake hazard in Israel, it is now worth considering what can be done to reduce the vulnerability of Israeli cities to earthquake damage.

As early as 1928, Willis had the following to say about standards of construction in Israel:

"The Zionists are building a new city, Tel-el-vir, as a suburb to Jaffa. It is a beautiful city to look at, but it is not built to withstand an earthquake. Jerusalem is spreading out in suburbs which are not put up to withstand an earthquake of any severity. The risks are growing rapidly with the increase in population and wealth, and no one knows whether or not or when a destructive earthquake may strike" (p.97).

In recognition of the threat posed by earthquakes to construction in Israel, The Standards Institution of Israel has produced a code for earthquake resistant design and construction. The code was published in November, 1975, but the uniformity with which it has since been applied is unfortunately not known. The code was introduced at a time of general deterioration in standards of construction in Israel. This deterioration had been noticeable over a 10 year period, and was attributed to ever increasing pressure of population and time. This pressure is, if anything, greater today than ever before. It is to be hoped that the use of poor construction practices is not continuing, in an attempt to develop new centres of population, or expand existing ones, in too short a time period.

Particular attention needs to be focussed upon the following aspects of construction in Israel:

- Height of construction;
- Building design;
- Location of important services.

8.9.1 Height of construction

The 1985 Mexican earthquake served to highlight the vulnerability of medium and high-rise structures to ground motions emanating from a distant earthquake source (see Section 2.13.2 and Figure 2.13). Buildings in this height range are more sensitive to the longer period and duration of shock waves associated with a distant event, than are low-rise buildings.

This observation is of great relevance to the cities of Israel, particularly those situated in the coastal region. As discussed in Sections 6.2.1 and 8.5.1, this part of the country is vulnerable to earthquakes originating far offshore. It is therefore of concern to note that in recent years there has been a trend towards increased height of construction in Israeli cities. Since the 1960's, major urban centres such as Tel Aviv and Haifa have been undergoing gradual redevelopment. This has involved the demolition of many of

TABLE 8.3

A Comparison of the Heights of Buildings Constructed in Israel in 1978 and 1981

NUMBER OF STOREYS	NUMBER OF BUILDINGS COMPLETED 1978	1981	% CHANGE OVER THREE YEARS
1	835	574	-31%
2	652	520	-20%
3	314	275	-12%
4	378	441	+17%
5-7	355	335	- 6%
8+	108	156	+44%

Source of data: Central Bureau of Statistics (1982; p.475) the old one and two storey residential buildings of the early settlers. These have been replaced by modern multi-storey business premises and apartment blocks (see Plate 8.3). In the cities along the Mediterranean coast (where population density is highest), a distinct increase in the number of storeys in newly erected buildings can be observed. The number of high-rise hotels in resort towns such as Tiberias, Nahariyya and Eilat increases every year.

The trend towards increased height of construction in Israel is illustrated by Table 8.3. This shows that between 1978 and 1981, there was a 44% increase in the number of Israeli buildings constructed with 8 or more storeys. In contrast, there were 31%, 20% and 12% decreases in the numbers of buildings erected with 1, 2 and 3 storeys respectively. The average height of completed buildings in 1981 was 3 storeys, compared to 2.6 storeys in 1978.

In Section 2.10.3 it was shown that high-rise buildings are particularly vulnerable to distant earthquakes when they are situated upon thick sequences of unconsolidated sediment. This is because of the lower natural frequencies of vibration associated with this type of ground. Under such circumstances, the dangers of resonance coupling between the earthquake shock waves, the subsoil and the building need to be considered (see Section 2.13.3). If possible, high-rise structures exposed to the earthquake hazard should not therefore be erected in areas that provide unstable geological foundations. One such area in Israel, that has already been discussed in considerable detail, is Haifa Bay (see Section 8.7.2 and Figure 8.9).

PLATE 8.3

The sea front at Tel Aviv, looking in a northerly direction. The photograph reflects the trend towards increased heights of construction in the city. The foreground has been cleared of old one and two storey residential buildings (similar to those situated in the right of the picture) to make way for high-rise developments.

M.R.Degg (March, 1987)

PLATE 8.4

A 6 storey residential building in Tel Aviv showing the type of "soft" ground floor storey that is typical of construction in Israel.

M.R.Degg (March, 1987)

At present, development in the Haifa Bay area is predominantly low to medium-rise. Some high-rise development has occurred in the past (e.g. the power station and oil refineries, and the residential buildings of Qiryat Hayyim). Due to the threat posed by distant offshore earthquakes to the bay area, it is to be hoped that particular care has been taken in the design and construction of these buildings. Wherever possible, building foundations in the bay area should pierce through the alluvium into the underlying limestone in order to increase structural stability. The potential for building-subsoil interaction also needs to be examined and, if necessary, accounted for.

Similarly, the Old City district of Tiberias has very insecure geological foundations (see Section 8.7.3 and Figure 8.10). Several high-rise hotels have been erected in the district in recent years, and others are currently under construction (see Plate 8.1). Once again, it is to be hoped that adequate attention has been paid to the design and construction of the buildings, to ensure that they are capable of withstanding the strong intensities of ground motion that can be expected across this zone (e.g. due to an earthquake along the rift valley, or a large event in the eastern Mediterranean basin).

Unless careful precautions are taken in the design, construction and location of buildings, the increasing elevation of modern Israeli cities will undoubtedly serve to increase their vulnerability to earthquakes.

PLATE 8.5

A residential building on Mount Carmel (Haifa) with a "soft" ground floor storey.

M.R.Degg (March, 1987)

PLATE 8.6

A fire station (Number 4 on Figure 8.9) situated in the bay area of Haifa. The building has a "soft" ground floor storey and is also asymmetrical. It can therefore be expected to perform very badly in the event of an earthquake.

M.R.Degg (March, 1987)


נהג נכבד

8.9.2 Building design

Many modern buildings in Israel typically have an open ground floor storey that is used either as a parking-lot, or for storage (see Plates 8.4 and 8.5). The 1985 Mexican earthquake served to highlight that this design of building is very vulnerable to earthquakes because it is "top heavy" (see Section 2.11.2). The upper floors are supported by a "soft" ground storey, the columns of which are inadequately braced and therefore liable to fail when subject to strong lateral earthquake ground motions.

It is of particular concern to note the use of this design in medium-rise buildings. Even more disturbing is the construction of buildings of this type on steep slopes. For example, on the side of Mount Carmel (see Plate 8.5), and along the side of the rift valley in Tiberias. Such buildings present an unnecessarily high risk, and only serve to increase the vulnerability of Israeli cities to earthquakes.

8.9.3 Location of important services

The vulnerability of a city to earthquakes can be substantially reduced, if the "life-line" services on which the city depends are sensibly located and constructed (e.g. the emergency services, power stations and important communication links).

In many Israeli cities, services of this type have been erected without due care and attention. For example, in Haifa it is of concern to note that the power station that provides the city with its electricity is located in the centre of the hazardous bay area. In addition to this, a fire station (see Plate 8.6), major hospital and the bus and railway terminals are all situated on reclaimed alluvial land at the foot of Mount Carmel (see Figure 8.9). At the very least, serious disruption to all of these services can be expected in the event of a major earthquake striking the city. The oil refineries and petrochemical plants of the bay area could also be badly affected, triggering large fires and explosions.

By way of contrast, most of the rescue services in Tiberias have rightly been situated in the Uptown district. As discussed in Section 8.7.3, this part of the city is relatively secure.

The vulnerability of Israeli cities to earthquakes is undoubtedly increased by their susceptibility to earthquake-induced fire. This stems from the fact that most domestic gas in the country is supplied by pipeline (unlike the situation in Mexico - see Section 2.4.5.6). Such pipelines are very susceptible to rupture during earthquakes.

8.9.4 The role of the insurance industry

Insurers and reinsurers have a vital role to play as far as reducing the vulnerability of Israeli cities to earthquake hazard is concerned. By refusing to provide coverage for individual risks that show poor aspects of design, construction or location, they can help to stimulate improved building standards throughout the country (as well as reduce their own vulnerability to unnecessary loss).

8.10 CONCLUSIONS

The purpose of this chapter has been to apply the R.O.A. earthquake hazard zonation scheme (as described in Chapter 7) to a Middle Eastern country, namely Israel. This is one of several countries that was shown to be exposed to considerable earthquake threat in Part A of the Middle Eastern hazard analysis.

Using Israel as a case-study, a hazard zonation has been produced according to the R.O.A. scheme. The validity of this zonation has been examined, and it has been used as the basis for an insurance-oriented analysis of earthquake hazard and risk in the country. In the light of this analysis, the measures that need to be taken in order to reduce vulnerability to earthquake hazard in Israel have been discussed. It is to be hoped that the procedures outlined in this chapter will be applied to the other parts of the Middle East that are exposed to the earthquake threat (as identified in Part A of the analysis).

The major conclusions to be drawn from the chapter are as follows:

a) Israel as a whole is a country of moderate seismicity, situated between the relatively high levels of activity in the Alpide belt to the north, and the low levels in Arabia to the south-east. The major tectonic zones that affect the country are those of the offshore Mediterranean basin, and the Jordan rift valley. Since the foundation of the State of Israel in 1948, the country has not experienced a major earthquake event. However, insurers and reinsurers should not underestimate the potential earthquake threat facing large parts of the country. The historical record shows that the region has experienced a large number of devastating earthquakes in the past, and there is no reason whatsoever to assume that these will not continue to occur in the future.

b) The earthquake hazard zonation of Israel that has been produced using the R.O.A. scheme, is a considerable refinement upon any previous zonations of the country for insurance/reinsurance purposes. The zonation clearly serves to highlight the areas of greatest earthquake hazard, where insurers and reinsurers need to be particularly wary of their commitments. More detailed investigations then need to be carried out within these high hazard areas. The accuracy of the zonation serves to demonstrate the validity of the R.O.A. zonation scheme.

c) Despite the small size of Israel, the R.O.A. zonation shows that the severity of earthquake hazard varies quite considerably across the country, from areas with a probable maximum intensity (once every 50 years, on average) of grade VI, to areas with grade X. The severity of the hazard is controlled by proximity to the major tectonic zones, and by variations in surficial geology which serve to render some areas more susceptible to severe ground motions than others. The regions of greatest earthquake hazard are:

- the Jordan rift valley;
- the Valley of Jezreel;
- the coastal region.

The zonation shows that earthquake hazard is generally much less severe along the north-south trending highland axis of the country, and is least in the central southern region.

d) By relating the R.O.A. hazard zonation of Israel to the distribution of major centres of population, it is possible to define areas of relative earthquake risk in the country.

The risk of earthquake loss accumulations is greatest in the coastal region. This is because of a combination of high hazard status and high population densities. In contrast, although the Jordan rift valley and the Valley of Jezreel are areas of high earthquake hazard, large loss accumulations in these areas are less likely at present due to lower population densities. Obviously, as new developments occur in these areas, then the risk of large earthquake losses will increase. The hazard map can therefore be used by insurers and reinsurers to predict the effect that such developments will have upon the distribution and accumulation of risk.

Earthquake risk is low over much of the highland region of Israel. This is because the region is sparsely populated and has a relatively low hazard status. However, some centres of population do occur in areas of relatively high hazard, and could result in large losses.

There is very low potential for large earthquake loss accumulations in the central southern part of Israel. This is due to a combination of very low population densities and low hazard status.

e) The R.O.A. hazard zonation serves to provide insurers and reinsurers with a general impression of the exposure of Israeli cities to earthquake hazard. Within the cities, detailed analysis of local geological conditions is then required in order to delineate earthquake hazard more precisely. It is essential that microzonation maps are produced on the city scale. These should attempt to show exposure to earthquake-related hazards, such as landslides, tsunamis, seiches and liquefaction.

The use of microzonation maps, combined with stringent design and construction regulations, could do much to reduce the vulnerability of Israeli cities to earthquake hazard. It is only by paying careful consideration to such factors, that insurers and reinsurers can make certain that their future earthquake losses in the country are kept to an absolute minimum.

CHAPTER 9. THE CONTROL OF EARTHQUAKE RISK

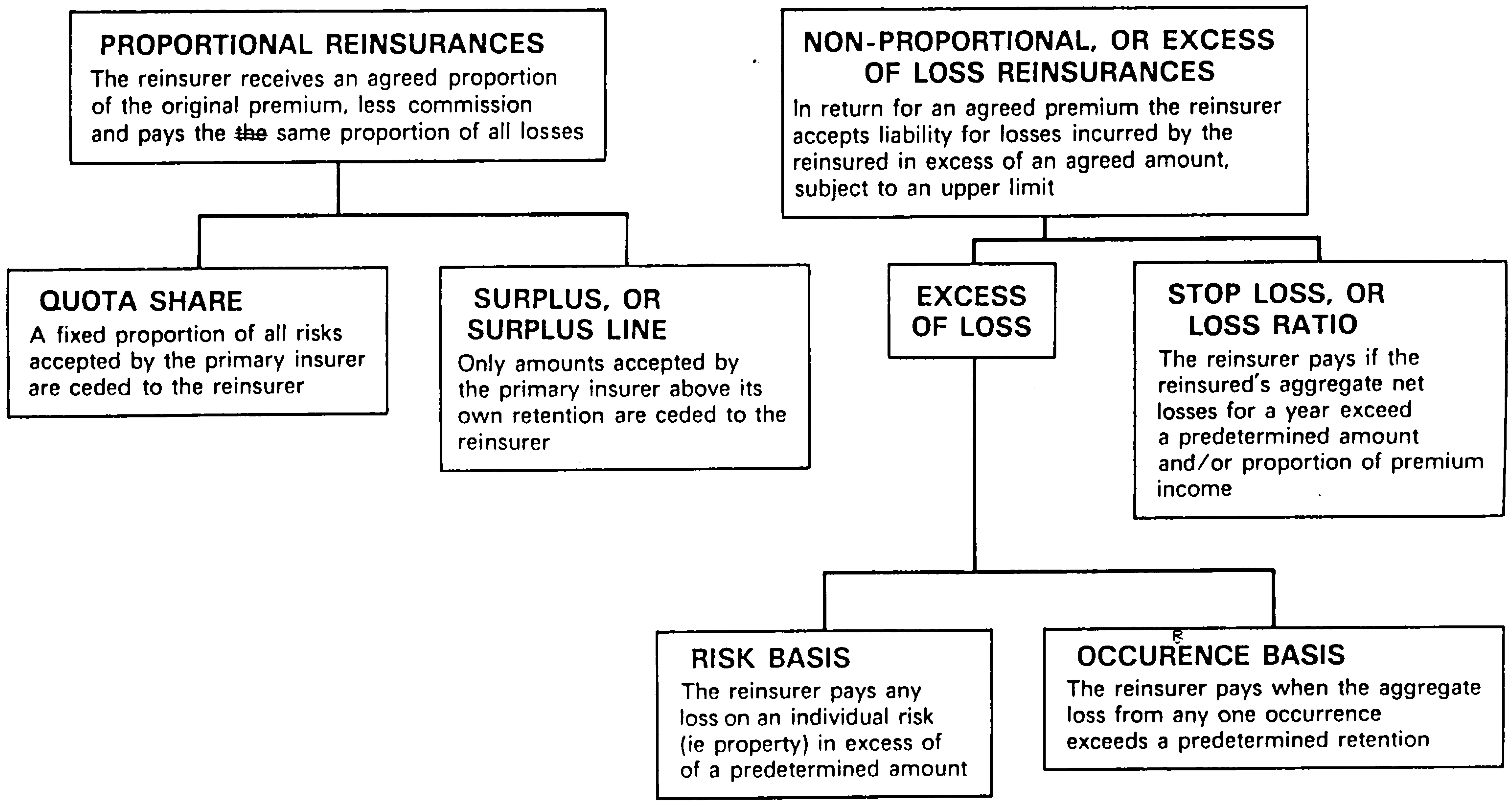
9.1 INTRODUCTION

The previous chapters have presented data and techniques concerning various aspects of earthquake hazard and risk assessment. The purpose of this chapter is to place this material in context, by showing how it can be incorporated in standard insurance/reinsurance procedures aimed at controlling earthquake risk (i.e. rating and accumulation control).

The chapter begins by summarising the characteristics of earthquake hazard that are of particular importance to the insurance industry. Direct underwriting aspects of the hazard are then discussed. Particular attention is focussed on the calculation of premiums to cover earthquake risk. A method of premium calculation is presented that can be used in conjunction with the R.O.A. scheme for earthquake hazard zonation. Possible applications of the technique to the production of standardised rate schedules are discussed.

The second half of the chapter is concerned with the assessment and control of earthquake risk accumulations. Implications of earthquake catastrophes for the insurance industry are discussed. A summary is then given of the principles of earthquake accumulation assessment, and of the assessment techniques that are currently in use. In the light of this discussion, a new approach to earthquake accumulation assessment is described, based upon the R.O.A. scheme for earthquake hazard zonation. The potential for the development of a computerised risk assessment procedure that uses this technique is highlighted.

Figure 9.1 Forms and types of reinsurance



After Carter (1983, p.70), as reproduced in Arnell (1983, Fig.3)

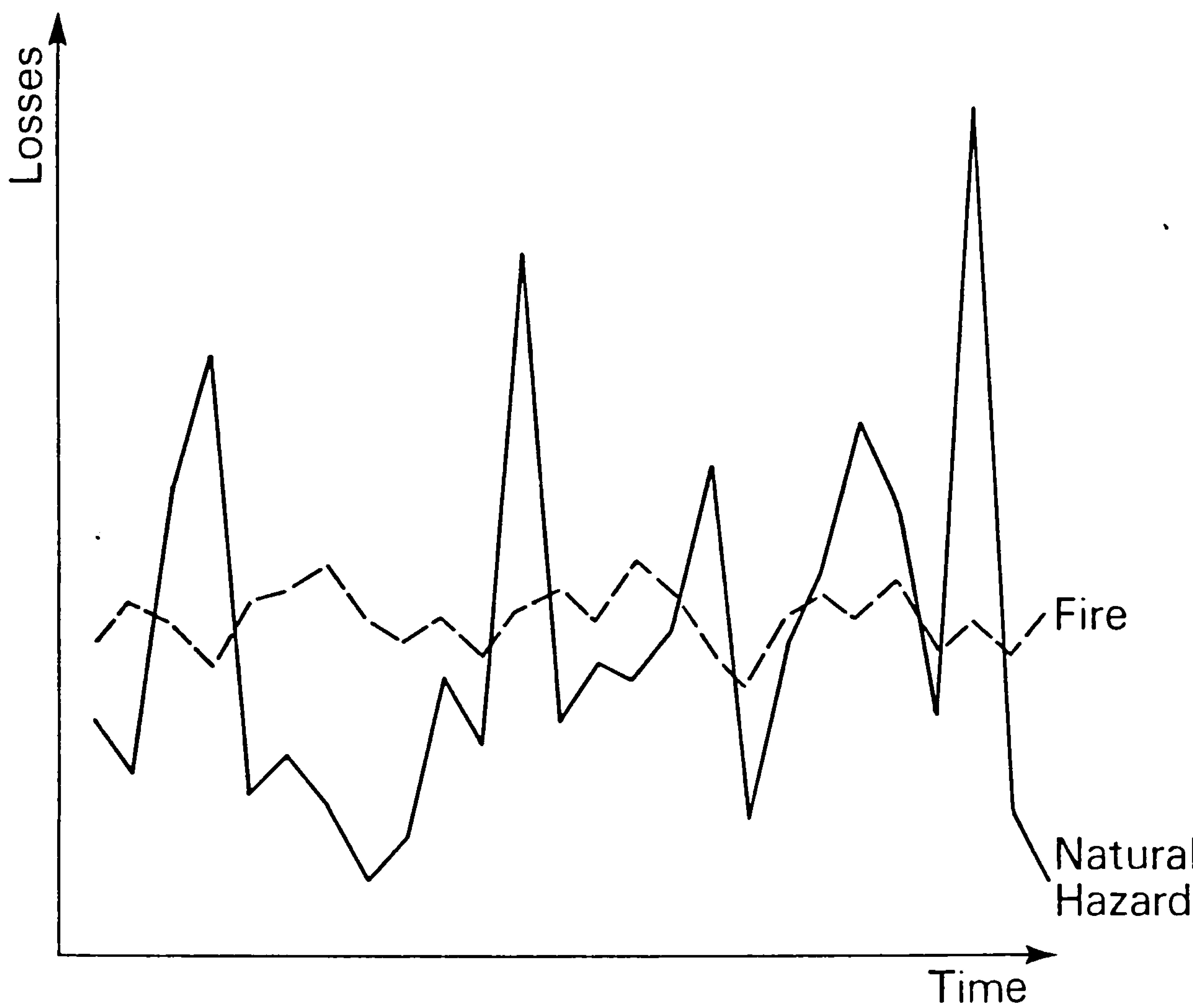
The chapter concludes by analysing the role of the insurance industry in helping to curb increasing exposure to earthquake hazard in regions like the Middle East.

9.2 EARTHQUAKE HAZARD AND THE INSURANCE INDUSTRY

Insurance is one of several possible responses to earthquake hazard. When an individual buys insurance, he is effectively transferring the cost of loss (or part of it) to the insurance company. In return for this service, he pays the insurance company a premium. In a similar way, an insurance company can insure itself with a reinsurance company against the possibility of having to pay out large sums of money due to earthquake-inflicted losses. Reinsurance can therefore be defined as "the insurance of contractual liabilities incurred under contracts of direct insurance or reinsurance" (Carter, 1983; p.4). Insurance spreads the cost of an individual earthquake loss over a large number of policyholders. Reinsurance spreads the loss still further, especially if the reinsurance company itself buys reinsurance, as is often the case (Arnell, 1983).

There are several different types of reinsurance treaty (see Figure 9.1). Earthquake reinsurance is generally sold as "excess of loss" reinsurance, normally on a loss occurrence basis. The reinsurer agrees to pay the insurer when the total retained loss due to any one earthquake event (during a specific time period) exceeds a predetermined retention level (Arnell, 1983). It is therefore imperative that both the insurer and reinsurer have fully ascertained their exposure to the earthquake hazard before they

Figure 9.2 Hypothetical losses from fire and a natural hazard



After Arnell (1983, Fig.2)

enter into such an agreement.

9.2.1 Particularities of earthquake hazard insurance

Earthquake hazard insurance (like other types of natural hazard coverage) is different from many conventional insurance lines in three important ways:

a) With earthquake hazard there is the potential for extremely large (catastrophic) losses;

b) Earthquakes show considerable temporal variation;

c) Earthquakes show considerable spatial concentration.

The effect that factors (a) and (b) have upon loss experience is illustrated in Figure 9.2. Clearly, the losses caused by earthquakes will be a lot more erratic in both time and size, than those experienced as a result of more conventional perils like fire and theft. The spatial concentration of earthquakes (factor (c)) also has several implications for insurance. Most important of these is the fact that only those people who perceive themselves to be most exposed to the earthquake hazard will consider buying insurance cover. Thus, the policyholder base is relatively narrow, and consists largely of "bad risks". The ratio of claims to premiums is therefore high for many earthquake catastrophes (Arnell, 1983).

As a result of this, earthquake insurance does not always seem to obey the basic tenet of insurance, whereby "the premiums of the many pay for the losses of the few" (Thorne, 1984; p.174). It is for this reason that earthquakes (on a par with other natural hazards) call for insurance techniques of their own, which take into account the particularities of the hazard.

9.2.2 Insuring against earthquakes

From the discussions in Chapters 7 and 8, it is apparent that earthquake risk (in insurance terms) is dependent upon:

a) The frequency, severity and geographical extent of the earthquake hazard;

b) The type, distribution and value of property and/or people exposed to the hazard (i.e. the nature of the inventory);

c) The amount of loss that is likely to be associated with a given severity of the hazard (i.e. the vulnerability of the inventory to the hazard).

It is now widely accepted that in order to provide insurance cover for earthquakes, two measures of earthquake risk are required (Munich Re., 1978; Smolka and Berz, 1981; Friedman, 1984):

- the risk per insured liability (<u>premium rating</u>);

- the risk of a large number of simultaneous losses stemming from a single earthquake event (<u>accumulation assessment</u>).

The first measure is based upon the average annual loss that can be expected per insured liability. It is used to derive premium rates that are commensurate with the risk. The second measure provides an indication of catastrophe potential. It allows conclusions to be drawn concerning extreme earthquake events with long return periods, and about the loss burdens to be anticipated as a result of their occurrence. The assessment of catastrophe potential is of crucial importance, because it provides a means of incorporating the extremes of the earthquake hazard (referred to in Section 9.2.1) in the risk analysis. It also serves to dictate how much of a financial reserve is needed to cover possible major losses on an insurance portfolio (Friedman, 1984). As such, catastrophe potential forms the basis upon which insurers decide whether or not to buy reinsurance (and if so, how much).

Friedman (1984) has shown that the two measures of earthquake risk are not directly related. The size of the expected average annual earthquake loss, does not necessarily imply the magnitude of the catastrophe potential. These two aspects of earthquake risk will be discussed in greater detail in the following sections.

9.3 EARTHQUAKE PREMIUMS (RATING)

Earthquake damages can be divided into those that are tangible, and those that are intangible (Arnell, 1983). Tangible damages are ones to which monetary values can be assigned. They can be further subdivided into direct and indirect damages. Direct damage is the damage to property (or loss of life) caused by an earthquake event. Indirect damage includes the cost of disruption caused by an earthquake. <u>Intangible damages</u> are those to which monetary values cannot easily be assigned. They include, injury, illness, shock and stress.

The most obvious and widespread use of earthquake insurance is to reimburse direct damages to buildings. The discussion in the remainder of the chapter will therefore be oriented towards building insurance (the same principles can be applied to the insurance of other structures, such as bridges and pipelines). However, it should be borne in mind that a variety of other lines of insurance may provide cover for earthquake loss. These include:

- policies covering the contents of buildings;
- vehicle policies, including those covering goods in transit;
- "all-risk" policies protecting valuable items;
- "Contractors All Risks" (C.A.R.) and "Erectors All Risks" (E.A.R.) policies covering buildings and other structures during construction;
- life and personal accident insurance policies;
- policies pertaining to marine and aviation insurance;
- policies protecting credit agreements;
- "consequential loss" policies covering indirect damages such as lost business and production.

Detailed discussion of these additional types of earthquake coverage is beyond the scope of the present study.

9.3.1 Premium rate calculation

According to Lockett (1980), three principles underlie the calculation of earthquake premium rates. These are:

a) Total premium income must be adequate to cover liabilities (i.e. annual expected losses) and expenses;

b) Ideally, premiums must not be so high that people become unwilling to pay (there are exceptions to this - see Section 9.7);

c) The premium structure should ensure fairness amongst policyholders, by reflecting differences in the degree of hazard to which properties are exposed.

It is possible to calculate earthquake premiums on a rational basis using both geological and economic data. The premiums should be based upon predicted average annual losses, and incorporate loadings for the following:

- administrative costs and profit;
- the effects of deductibles (a deductible represents a reduction in the insurer's liability, and therefore qualifies for a premium discount);
- reinsurance premiums;
- the uncertainties inherent in any hazard intensity-frequency relationship;
- the effects of taxation - in the U.K. and many other countries, contributions to "catastrophe"/"claims equalisation" reserves are

not tax deductible.

The majority of premium formulae (e.g. those of Arnould, 1976; Swiss Re., 1977; Munich Re., 1978 and Sauter, 1979), can be reduced to the following expression:

$$P = \sum_{i=0}^{i=Imax} \left[\frac{LE}{SI \times RP} \right]_i + L$$

where:

P = Gross annual premium rate. This is normally expressed as percent of SI (multiply P by 100), or permille of SI (multiply P by 1000);

i = Intensity (of earthquake);

RP = Return period of an earthquake with intensity (i);

LE = Loss expected for an earthquake of intensity (i);

SI = Sum insured, given as an amount if the loss (LE) has been expressed as a sum of money, or 100 if the LE is expressed as a percentage;

Imax = Probable maximal intensity of earthquake;

L = Loading to cover the items listed above.

The purpose of the first term in the expression is to take into consideration the fact that during the return period of an earthquake of maximal intensity, damaging events of lower intensity can occur. The expression only applies to the calculation of premiums for fixed property. Premium rates for the insurance of buildings during their construction (normally covered by Contractors All Risks policies) are more complicated, as the sum at risk varies throughout the construction process (Swiss Re., 1976).

In order to calculate earthquake premiums for buildings, data clearly have to be available concerning both the hazard intensity-frequency relationship, and the loss susceptibility (vulnerability to damage) of different construction types/property groups.

9.3.1.1 The hazard intensity-frequency relationship

This relationship has to be derived from an appropriate earthquake hazard zonation. In this context, a zonation produced using the R.O.A. scheme (see Section 7.7) is ideally suited to the calculation of earthquake premiums. This can best be illustrated by reference to the R.O.A. hazard zonation of Israel presented in Chapter 8 (see Figure 8.4).

As discussed in Section 8.5.1, the zonation divides Israel into a number of hazard zones (on the basis of the maximum intensity of ground shaking to be expected once in 50 years). These zones provide insurers and reinsurers with the necessary intensity-frequency data on which to base premium calculations. For important risks, more precise hazard zonations may be required, such as those presented in Figures 8.9 and 8.10 (for full discussion, see Sections 8.7 and 8.8). Hazard exposure values obtained from the zonation maps should then be combined with standardised loss-susceptibility data, in order to calculate the earthquake premiums that need to be charged.

9.3.1.2 Loss-susceptibility data

The vulnerability of buildings to earthquake damage varies according to type and height of construction. This was highlighted by the damage experience of the 1985 Mexican earthquake (see Section 2.13.2 and Figure 2.13).

Earthquake vulnerability analysis aims to assess (and/or forecast), the structural and non-structural damage that buildings will experience during earthquakes. According to Boissonnade and Shah (1984), there are two main approaches to vulnerability analysis:

a) The theoretical approach - this attempts to predict the response of a structure to earthquake ground shaking using a theoretical model. It is often used when analysing the vulnerability of valuable and important structures;

b) The empirical approach - this attempts to correlate a measure of ground motion severity (e.g. intensity), with a damage severity index for a particular type of construction. The index is usually based upon statistical observations of the effects of past earthquake events. Engineering judgement is used to supplement inadequacies in the historical data.

For the vast majority of buildings, the empirical approach to vulnerability analysis is sufficiently accurate for insurance rating purposes. There have, therefore, been a number of insurance-oriented studies of this type in recent years (e.g. Algermissen and Steinbrugge, 1978; Algermissen et al., 1978; Sauter and Shah, 1978

TABLE 9.1

Loss-Susceptibility Data for Different Construction Types

CONSTRUCTION TYPE	AVERAGE LOSS EXPECTED (%) AT INTENSITY (MM)				
	VI	VII	VIII	IX	X
1. Adobe	8	22	50	100	100
2. Unreinforced Masonry, Non-Seismic Design	3.5	14	40	80	100
3. Reinforced Concrete Frames, Non-Seismic Design	2.5	11	33	70	100
4. Steel Frames, Non-Seismic Design	1.8	6	18	40	70
5. Reinforced Masonry, Medium Quality, Non-Seismic Design	1.5	5.5	16	38	66
6. Reinforced Concrete Frames, Seismic Design	0.9	4	13	33	58
7. Shear Wall Structures, Seismic Design	0.6	2.3	7	17	30
8. Wooden Structures, Seismic Design	0.5	2.8	8	15	23
9. Steel Frames, Seismic Design	0.4	2	7	20	40
10. Reinforced Masonry, High Quality Seismic Design	0.3	1.5	5	13	25

Source of data: Sauter and Shah (1978)

and Sauter, 1979). The work of Algermissen and his co-workers is largely specific to the San Francisco region of the U.S.A. That of Sauter and Shah is more universally applicable. They have presented a valuable summary of damage statistics for construction types in common use throughout the world (see Table 9.1). When combined with appropriate hazard zonations, these data form the ideal basis for a rational approach to earthquake premium calculation.

Hazard zonations produced using the R.O.A scheme are compatible with the loss-susceptibility data presented in Table 9.1. This is because they use intensity as the zoning parameter.

9.3.2 Using a hazard map produced according to the R.O.A. scheme to derive earthquake insurance premiums

The purpose of this section is to show how data taken from a hazard map produced according to the R.O.A. scheme (i.e. that of Israel - Figure 8.4), can be used in the calculation of reliable earthquake premiums. The method of premium calculation that has been adopted here is one described by the Munich Re. (1978), based "on sound underwriting considerations" (p.12). It follows the principles discussed in Section 9.3.1, and satisfies all the basic requirements of premium calculation. The method can be applied internationally.

9.3.2.1 Interpreting the loss-susceptibility data

The net basic annual premium for a building is calculated as the sum of the losses expected (LE) in a specific period of time, divided by the number of years in that period, and increased by a fluctuation loading that makes allowance for the irregular occurrence of earthquakes. The LE depends upon the earthquake intensity, and the construction methods used (i.e. the severity of the hazard, and the vulnerability to the hazard).

In Table 9.1, LE statistics are given as percentages. They relate to particular intensities of ground shaking (on the Modified Mercalli scale), and represent average values obtained from a comprehensive analysis of world-wide loss experience. In individual cases the loss ratios may need to be increased or decreased depending upon a number of factors. These are discussed in detail by the Swiss Re. (1977) and Porro (1984), and include:

- building age;
- building and facade design;
- construction supervision and workmanship;
- quality of materials used;
- regularity of the structure;
- spacing between adjacent structures;
- exposure to fire;
- weakening caused by earlier earthquakes.

For example, Table 9.1 indicates that a building of construction type 10, may be expected to experience 5% damage when subject to intensity VIII. However, if the building is of particularly good design and construction for its class, it may be appropriate to apply the LE ratio of the next intensity grading down the scale. This would give a LE of 1.5% for intensity VIII. Similarly, if the building is of particularly poor construction, the LE ratio of the next intensity grading up the scale should be applied (i.e. 13%). In view of this, it is important for an underwriter or engineer to have good technical data at his disposal when assessing a building for rating purposes (Munich Re., 1978).

9.3.2.2 Relating an R.O.A. hazard zonation to the loss-susceptibility data

A hazard map produced according to the R.O.A. scheme provides an assessment in terms of the maximum intensity of ground shaking to be expected on average once in 50 years (see Section 7.7). Hence, it can be used to determine the maximum amount of damage (from a single earthquake event), that a building can expect to experience during this time period. For example, by combining data from Figure 8.4 (R.O.A. zonation of Israel) and Table 9.1, it can be determined that in Eilat a high-rise building of construction class 10 has an average maximum LE of 13% once in 50 years. An identical building in BeerSheva has a corresponding LE of 1.5%.

The once-in-50 years average LE is not an entirely satisfactory estimate of expected earthquake loss. This is because within the 50 year return period, several events of lower intensity are likely to occur. Events of higher intensity may also be experienced. For important risks, it is essential that the threat from these additional events is taken into consideration by carrying out site-specific frequency analysis. For the majority of buildings, however, the additional risk can be covered quite adequately by assuming that the total loss in 50 years will be three times the once-in-50 years LE (Munich Re., 1978). Hence, for the building in

BeerSheva cited in the example above, the total LE for a 50 year period is 3 x 1.5 = 4.5%. The annual LE is then 4.5%/50 = 0.09% (0.9 permille).

9.3.2.3 Incorporating the annual LE in premium calculation

The annual LE of a building forms the basis of the premium calculation. As mentioned in Section 9.3.1, a number of loadings have to be added to the annual LE to derive a premium. These include loadings for the following:

a) Fluctuations and insurance density

Premium calculations need to consider the uncertainties inherent in the hazard intensity-frequency relationship. These uncertainties cause the results of earthquake insurance to fluctuate greatly from year to year, making a particularly cautious underwriting policy necessary. In order to account for them, the Munich Re. (1978) suggest that a fluctuation loading of 10% must be added to the annual LE. They further suggest that if a number of insured risks are concentrated within a small area, an additional loading (of 10% of annual LE) is required to cover the dangers of high premium density;

b) The height of buildings

The 1985 Mexican earthquake demonstrated that medium to high-rise buildings (>5 storeys) are sensitive to earthquakes over much greater distances than low-rise buildings (see Section 2.13.2 and

Figure 2.13). They therefore respond to more earthquake events. In view of this, the Munich Re. (1976; 1978) suggest that a 20% loading should be added to the annual LE of medium to high-rise buildings;

c) Costs, profits and restrictions on the scope of cover

A loading must be added to cover the administrative costs and profits of the insurance company. The size of this loading will obviously vary from one company to another. Similarly, company policy will dictate the size of deductibles and limits of liability that are incorporated in the premium to restrict the scope of cover. The policy conditions are so manifold in this respect, that it is impossible to generalise the size of the loadings.

9.3.2.4 An example of premium calculation

To return to the example of the high-rise building in BeerSheva cited above, the premium calculation would be as follows (assuming that the building is situated in a conurbation):

Annual LE = 0.09% (see Section 9.3.2.2);

Plus loading for fluctuations, and for conurbations = 0.2 x 0.09% = 0.018%;

Plus loading for high-rise structures = 0.2 x 0.09% = 0.018%;

Annual basic premium (excluding costs, profit margins and deductibles) = 0.126% = 1.26 permille.

TABLE 9.2

A Simplified Rate Schedule for an Exposure Zone with a Maximum Expected Intensity of VIII Once in Fifty Years

	ANNUAL BASIC PREMIUM (PERMILLE)			
			WITH LOADING FOR CONURBATIONS	
CONSTRUCTION TYPE*	Low-Rise Structure (<5 Storeys)	Medium to High-Rise Structure (>5 Storeys)	Low-Rise	Medium to High-Rise
1	33‰	n/a	36‰	n/a
2	26.4	31.2‰	28.8	33.6‰
3	21.78	25.74	23.76	27.72
4	11.88	14.04	12.96	15.12
5	10.56	12.48	11.52	13.44
6	8.58	10.14	9.36	10.92
7	4.62	5.46	5.04	5.88
8	5.28	6.24	5.76	6.72
9	4.62	5.46	5.04	5.88
10	3.3	3.9	3.6	4.2

*See Table 9.1

NOTE: It is highly unlikely that buildings of construction type (1) will exceed five storeys in height

The figures for annual basic premium are exclusive of costs, profit margins and deductibles.

It must be stressed that the above calculation is based entirely upon "averaged" data, both in terms of hazard exposure and loss-susceptibility. Large and important risks clearly require site-specific analysis of the severity of the hazard and the vulnerability of the structure to the hazard. These should also examine the threat posed by earthquake-related hazards (e.g. tsunamis, ground failures, seiches and volcanic eruptions). The historical earthquake catalogues (Appendices A and B) contain pertinent data concerning these hazards in the Middle East (see Sections 5.7 and 8.8, and Figures 5.4 and 5.10).

9.4 STANDARD RATE SCHEDULES BASED ON R.O.A. HAZARD ZONATIONS

It is possible to simplify the earthquake rating process (and remove the need for repetitious calculation), by producing standard rate schedules (Arnell, 1983). For a given severity of earthquake hazard, these show the annual basic premium that needs to be charged for different types of building. The Mexican earthquake tariff presented in Table 2.6 is a good example of a rate schedule of this type.

Table 9.2 is an example of a simplified rate schedule that is intended for use with an R.O.A. earthquake hazard zonation (e.g. that of Israel - Figure 8.4). The schedule is based upon the loss susceptibility data listed in Table 9.1, and has been derived using the premium calculation procedure described in Section 9.3.2. It can be applied to all the exposure zones on Figure 8.4 that have an expected maximum intensity of VIII once in 50 years. Hence, the annual basic premium for a low-rise building (construction class 10) situated in the centre of Gaza is 0.36% (3.6 permille).

Once again, it must be stressed that the premium rates given in Table 9.2 are average values. They can be increased or decreased depending upon the particular characteristics of the building in question (see full discussion in Section 9.3.2.1). Site-specific analysis is required for important risks.

Ideally, an insurance company should produce its own rate schedules. These should be geared to satisfy the particular rating requirements of the company (i.e. to take into account the size of the deductibles that will be charged, profit margins, administrative costs, amount of competition from other companies etc.). If one rate schedule is produced for each of the five exposure zones shown on Figure 8.4, the application of earthquake premiums becomes extremely easy. All that an insurer then needs to determine a premium rate, is information concerning building type and location.

9.5 EARTHQUAKE ACCUMULATION ASSESSMENT

So far, discussion has focussed upon direct underwriting aspects of earthquake hazard. It has been shown how potential earthquake damage to individual structures can be assessed, and the results used to derive realistic earthquake premiums. As mentioned in Section 9.2.2, premium rating is the first measure of earthquake risk.

The second measure of earthquake risk concerns accumulation assessment (i.e. a measure of the potential for a large number of simultaneous losses stemming from a single earthquake event). A significant proportion of total earthquake losses are attributable to very large, but infrequent, catastrophic events (like the 1985

Mexican catastrophe). It is very difficult to obtain and maintain adequate rating levels that cover such earthquakes (Munkhammar and Themptander, 1984). Insurers and reinsurers therefore need to take great care in assessing and controlling their accumulations of earthquake liabilities.

Assessment and control of earthquake liabilities is especially important in those seismic regions of the world that have experienced rapid economic growth in recent years. As discussed in Chapter 3, the Middle East is one such region that is of particular concern because industrial development and urban expansion have been concentrated in selected areas (see Figures 3.2, 3.3, 3.5 and 3.6). Within these areas, accumulation of insured values is taking place. Since the demand for insurance is to a large extent income-related (Carter, pers.comm.), future growth in the prosperity of the region will undoubtedly serve to increase these accumulations still further.

9.5.1 Implications of earthquake catastrophes for the insurance industry

Earthquake catastrophes (in insurance terms) are caused by the interaction of the geographical pattern of severity of an earthquake event, with the spatial array of insured structures (Friedman, 1984). They pose particular problems for the insurance industry, most important of which is the need for insurers and reinsurers to be able to assess the probable maximum losses (PML's) that are likely to result from such occurrences. Accurate assessments of PML are of crucial importance, because it is on the basis of these that insurers and reinsurers decide how best to cover the catastrophe risk. For example, an insurance company will use them to decide what proportion of their insured risks can be retained for their own account, and the size of the reserves that they will require. If PML estimates are inaccurate, there is a danger that when a major catastrophe occurs, a number of risk carriers will fail to pay their share due to insufficient funds (Munkhammar and Themptander, 1984).

Direct insurers therefore need to assess their earthquake accumulations as accurately as possible. Such assessments are necessary not only for their own protection, but also to enable them to obtain secure catastrophe reinsurance. Thorne (1984) has pointed out that reinsurers are very often inadequately informed about the accumulation of risks exposed to the earthquake hazard. It is, therefore, relatively easy for them to become over-committed in a region without being aware of the fact. In the event of an earthquake catastrophe, reinsurance companies that have exceeded their limits could be faced with financial ruin, thereby placing in jeopardy the very insurance companies that they are supposed to be protecting. Clearly, the better informed the reinsurer is about his accumulated liabilities, the less likely he is to exceed his capacity. In recent years, more and more reinsurers have started to require that their ceding companies supply them with increased information regarding exposures (Carter, pers.comm.).

9.5.2 Assessing earthquake accumulations

A direct insurer usually has treaty connections with many reinsurers. These, in turn, participate in treaties with a large number of ceding companies. In order to control earthquake liabilities, it is essential that the data that passes between the companies is standardised, and presented in a uniform manner (Porro, 1984).

The Munich Re. (1976) have described an approach to earthquake accumulation assessment and control that attempts to provide such standardisation. It is based upon the delineation of two types of earthquake zone:

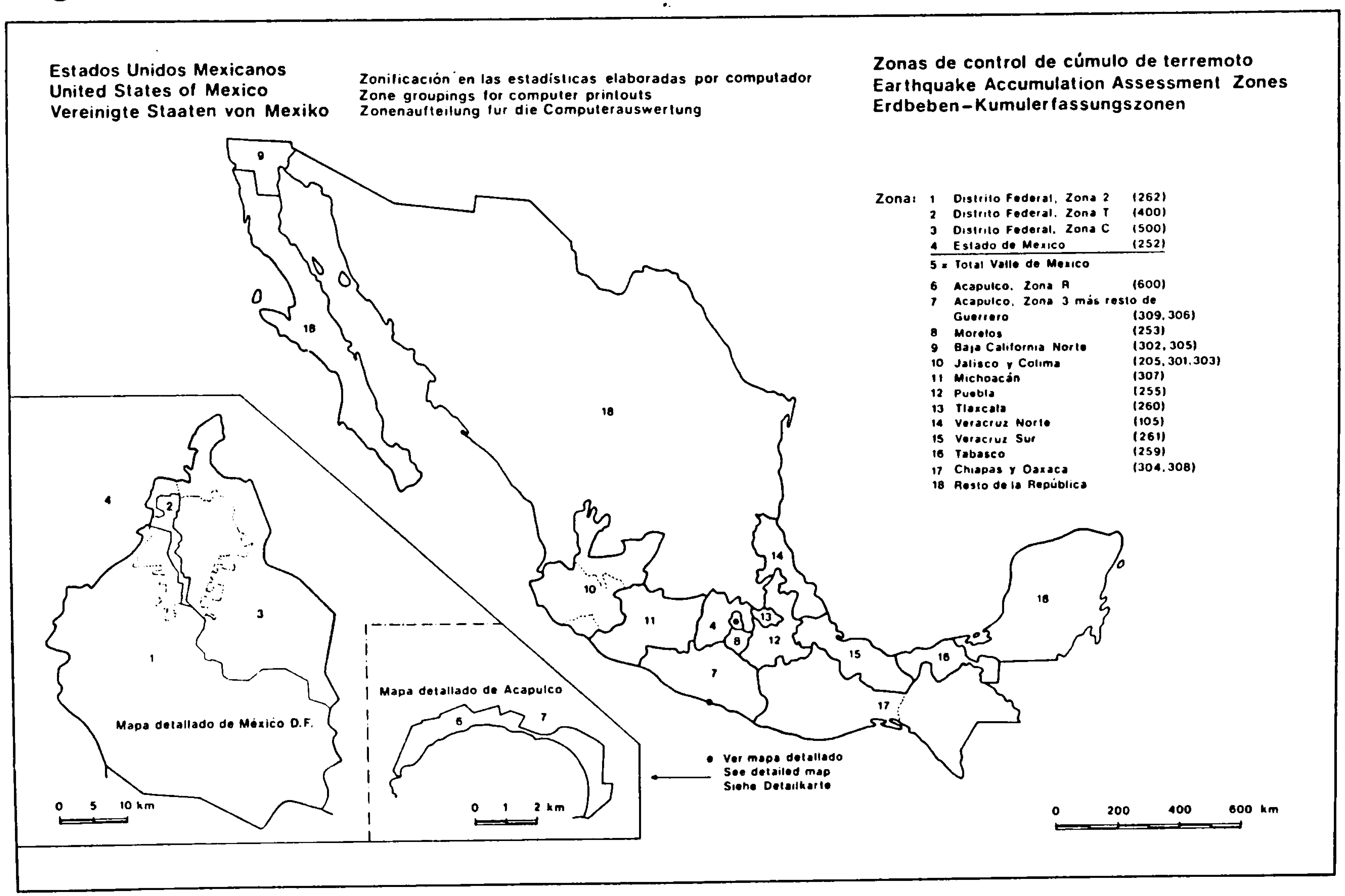
- accumulation assessment zones;
- loss accumulation zones.

9.5.2.1 Earthquake accumulation assessment zones

Regions that are exposed to the earthquake hazard should be divided into a suitable number of accumulation assessment zones (Berz, 1984). These are used by direct insurers and reinsurers to keep a tally of the risks that they run. For each accumulation assessment zone, an insurer should classify his liabilities according to their loss susceptibility (Berz, 1984). Average loss ratios (similar to those presented in Table 9.1), can then be applied to each class of liability in each accumulation assessment zone.

According to the Munich Re. (1976), the "division of a country into accumulation assessment zones, worked out together by all concerned - direct insurers and reinsurers alike - is the basic condition of successful accumulation assessment" (p.45). Indeed, accumulation control can only serve its purpose if the entire insurance market of

Figure 9.3 Accumulation assessment zones of Mexico



After Munich Re. (1986, p.64)

a country can agree upon a standard accumulation assessment zonation (Berz, 1984).

It was for this reason that the CRESTA (Catastrophe Risk Evaluating and Standardising Target Accumulations) programme was initiated by a group of direct insurers and reinsurers. The aim of the programme is to compile and standardise, for a number of countries, scientific and underwriting data concerning catastrophe exposure. The data include zonations for assessing earthquake accumulations. The accumulation assessment zonation of Israel that has been adopted by CRESTA is shown in Figure 8.8. The way in which this relates to the distribution of earthquake hazard and risk in the country was discussed in Section 8.6. Figure 9.3 shows the accumulation assessment zones of Mexico.

In addition to monitoring distributions of insured values, earthquake accumulation assessment zones are used to simulate the loss distributions of large earthquake events. This is done by creating loss accumulation zones.

9.5.2.2 Earthquake loss accumulation zones

Earthquake loss accumulation zones are made up of accumulation assessment zones. Each loss accumulation zone delineates an area that could be affected by a single earthquake event (though the intensity of shaking in the different accumulation assessment zones will obviously vary). The Munich Re. (1976) define loss accumulation zones as areas that will experience an intensity of VII or greater during a single earthquake event. They can overlap each other, and/or form distinct units.

Loss accumulation zones are used to ascertain the effect that large earthquakes will have upon a given distribution of insured values. They are created on the basis of historical earthquake experience and seismo-tectonic setting. A PML is calculated for each loss accumulation zone by summing the losses that will be experienced in accumulation assessment zones (Berz, 1984). Through this approach, an insurer is able to determine the nature of the most destructive earthquake that could affect his portfolio (i.e. the size, location and possibly the frequency of the event). He can also obtain a measure of the magnitude of the losses that are likely to be associated with this maximal earthquake.

The historical earthquake catalogues listed in Appendices A1 and B1 are of great value in the delineation of loss accumulation zones in the Middle East. By using the indexes to the catalogues listed in Appendices A2 and B2, it is possible for an insurer to abstract all pertinent historical data concerning the spatial extent of earthquakes in any Middle Eastern country. Analysis of these data will then help the insurer to decide the location and size of the loss accumulation zones needed to circumscribe areas that could be affected by a single earthquake event. The most damaging events for the insurer's portfolio can then be identified using the procedure outlined in the paragraph above.

For example, in the case of Israel, the historical earthquake catalogue contains 153 separate entries for the country. Analysis of these, combined with data concerning 20th century seismicity and tectonic setting (see Chapter 4), shows that much of the central and northern coastal region of Israel could be shaken by a single offshore earthquake of large magnitude (see full discussion in Sections 6.2.1 and 8.5.1). It would, therefore, be justifiable to place this entire region in one loss accumulation zone. Unfortunately, the standardised accumulation assessment zonation of Israel (see Figure 8.8) cannot be adapted to form such a loss accumulation unit. This problem will be discussed in greater detail in Section 9.6.

According to the Munich Re. (1976), it must be left to each individual insurance company to decide on the location and extent of the loss accumulation zones that they use in their risk analyses. This decision is dependent upon:

a) Portfolio composition (i.e. the geographical distribution, and type of risk). The loss-inflicting potential of an earthquake will vary from one insurance portfolio to another;

b) The attitude of the company towards underwriting (i.e. their readiness to take a risk). The more cautious the attitude of the insurance company, the larger will be the loss accumulation zones that they create.

It is therefore "neither meaningful nor necessary for a market to agree upon specific loss accumulation zones" (Munich Re., 1976; p.44). The zones must remain flexible, so that they can be altered with time to take into account changes in the infrastructure of a country (and the associated shift of values), and increased knowledge concerning earthquake hazard.

9.6 EXTENDING THE R.O.A. ZONATION SCHEME TO ACCUMULATION ASSESSMENT

From the above discussion it is apparent that the key to successful earthquake risk assessment (for insurance purposes) is standardisation. In order to achieve such standardisation in a region, it is necessary to produce earthquake exposure and accumulation assessment zonations that are acceptable to all concerned (i.e. to both insurers and reinsurers). To date, most zonations of this type have, for administrative purposes (and convenience sake), been based upon existing communal and political boundaries (e.g. see Figures 8.8 and 9.3). There are several major disadvantages to producing insurance zonations in this way:

- Administrative units are often very irregular in shape and size. They therefore result in insurance zonations that share these characteristics. As was shown in Section 9.5.2.2, earthquake accumulation assessment zones that are based upon administrative boundaries place severe restrictions on the shape and size of the loss accumulation zones that can be created out of them;

- Administrative and political boundaries are unstable, and change with time. Hence, insurance zonations based upon them may quickly become dated;

- In the case of earthquake hazard zonations, large inaccuracies can be introduced by "adjusting" exposure zones to match administrative units (as in Figure 2.25). Such zonations often fail to reflect in full, the available scientific knowledge concerning the distribution and severity of earthquake hazard (i.e. they are over-generalised).

The R.O.A. hazard zonation scheme aims to overcome these problems by employing a grid network as the basis for zonation (see Sections 7.7 and 7.7.1). The network is used to divide a country into a large number of units of equal area, to which hazard exposure values are then assigned (see Figure 8.4). In the light of the above discussions, it would seem that such units would also form an ideal basis for accumulation assessments. The scenario for comprehensive risk assessment based upon a grid network would be as follows:

9.6.1 Employing the grid system for comprehensive risk assessment

In order to standardise the system, insurers and reinsurers would need to agree upon an initial subdivision of a country into grid units of a suitable size (depending upon the quality and quantity of geological and insurance data available). This would probably involve producing a detailed base-map of the country, with a grid overlay. If the base-map were on the Universal Transverse Mercator projection, the lines of the overlay could be co-ordinated with lines of latitude and longitude. Each grid square of the network would then be assigned an index number for referencing purposes (co-ordinates could be used).

The standard grid network would then provide the basis for all hazard and risk assessments. Each grid unit would serve as both an earthquake exposure zone, and an accumulation assessment zone. The units would be used to store:

- standardised data concerning exposure to earthquake hazard (and other types of natural hazard);

- standardised rate schedules for the expected severity of hazard, similar to those described in Section 9.4;

- data concering an insurer's portfolio. Insurers would use the standard base-map to catalogue the nature of their liabilities (i.e. the numbers and types of risk) for each grid unit.

Such a system would allow very rapid premium calculation. In addition, loss accumulation procedures would be greatly facilitated due to the uniformity of the accumulation assessment zones, particularly if the grid units were kept as small as possible.

9.6.2 Computerisation of the risk assessment procedure

A major advantage of the grid system is that it is ideally suited to computerisation. Standardised computer grid networks could be produced for countries/continents with little difficulty. Once the types of data referred to in Section 9.6.1 had been stored in the computer, an insurer would be able to:

- obtain hazard exposure values very rapidly. In the case of exposure to a variety of natural hazards, a computerised grid system would allow the relative interaction between these hazards to be analysed, and appropriate hazard indices derived;

- derive earthquake premiums, simply by entering information concerning location and type of risk;

- monitor the distribution and composition of his portfolio. Changes in the portfolio could be recorded with relative ease;

- derive rapid accumulation assessments. The effects that changes in portfolio composition would have upon the insurer's accumulation situation could be assessed very rapidly;

- analyse loss accumulation, by using the computer to simulate a variety of large earthquake events affecting different grid units. These events could be based upon historical earthquake data stored in the computer.

If such a system were developed and introduced, it could lead to the complete standardisation of earthquake risk assessment. The transfer of data between companies would be facilitated, thereby enabling insurers and reinsurers to assess their liabilities more accurately (and keep their assessments up to date). Improved assessments would undoubtedly serve to reduce the vulnerability of the insurance industry to catastrophic earthquake losses. It is to be hoped that they would also serve to encourage insurers to take steps to curb increasing exposure to earthquake hazard.

9.7 THE ROLE OF THE INSURANCE INDUSTRY IN HELPING TO CURB INCREASING EXPOSURE TO EARTHQUAKE HAZARD

The insurance industry has a vital role to play in helping to stem the rapid escalation of earthquake risk that has recently been witnessed in regions like the Middle East. This can be brought about by sensible insurance marketing, based upon reliable assessments of earthquake hazard and risk.

9.7.1 Insurance and development in hazardous areas

A property insurer's liability for earthquake hazard often includes some or all of the following (Munich Re., 1976):

a) Direct damage caused by the shock;
b) Damage caused by fire following the earthquake;
c) Damage caused by tsunamis;
d) Damage caused by earthquake-triggered ground failure (e.g. landslide and liquefaction);
e) Damage caused by volcanic eruption.

Alternatively, insurance can be offered for each of the hazards separately.

Earthquake hazard insurance "guarantees" complete or partial reimbursement in the event of loss (subject, of course, to the terms, conditions and exceptions of the policy). It therefore helps to remove some of the uncertainty involved in buying property in a hazardous area. As a result, there is a danger that the provision of this type of insurance cover may (unwittingly) increase exposure to earthquake hazard, by stimulating encroachment into hazardous areas (Arnell, 1983). An individual may well be tempted to move into such an area, in the knowledge that his insurance policy will protect him from severe financial loss.

It is therefore essential that premium rates (especially those charged for new properties), reflect the severity of hazard to which a property is exposed. It is for this reason that the recent changes in the earthquake tariff of Mexico City (as discussed in Section 2.12.2) are to be welcomed - The rates charged for the hazardous lake zone (Zone C) are now much higher than those charged for the less exposed hill zone (Zone 2). By charging high premium rates, insurers can do much to help to discourage construction and new development in areas of high hazard.

A number of other measures can be implemented to curb any encouraging effect that insurance may have on development in hazardous areas. For example, insurers can refuse to provide hazard coverage in a region until local government authorities agree to restrict development in highly exposed areas (Arnell, 1983). By imposing large deductibles, insurers can place strict limits on the size of the insurance claims that are paid in areas of high earthquake hazard.

9.7.2 Insurance and damage mitigation measures

Earthquake insurance transfers the risk of loss from an individual to the insurance company. It stands to reason that if the individual is fully insured, he has little incentive to protect his property against damage. This is because he personally will suffer no financial loss in the event of an earthquake (Arnell, 1983).

By applying restrictive conditions to the provision of earthquake insurance, insurers can encourage the adoption of hazard mitigation measures. For example, the imposition of a deductible means that the risk of loss is shared between the individual (property owner) and the insurance company (Arnell, 1983). Such risk-sharing may encourage the property owner to seek protection against small losses, and also saves the insurance company the expense of dealing with small claims. Obviously, the deductible must be large enough to make the property owner believe that it is worthwhile adopting damage mitigation measures.

Arnell (1983) suggests that the level of earthquake insurance premiums can be used to encourage property owners to adopt measures to reduce vulnerability to loss. For example, the offer of a premium reduction may provide a policy holder with the incentive to adopt damage mitigation measures. Obviously, the greater the offered reduction in premium, the greater the incentive to take action. The policy holder would need to be informed of the type of hazard mitigation measures to take. Such information would come either from the insurance company, from a government agency or from an independent professional advisor.

The adoption of damage mitigation measures can be encouraged by a ruling that hazard insurance will only be sold to protected property. To be totally effective, such a ruling needs to be backed by government legislation. This would prevent unfair competition between scrupulous and non-scrupulous insurers.

9.7.2.1 Hazard mitigation at the planning stage

It is often very difficult, and non-economical, to modify existing buildings to resist earthquake damage. Under such circumstances, there is little that the insurer can do to encourage hazard mitigation measures.

An altogether better approach to hazard mitigation, is to require that all new buildings are designed and constructed to meet specific standards (building codes). These codes should be strict enough to ensure that buildings are capable of resisting the severity of hazard that is expected. In the absence of government legislation, insurers can do a great deal to encourage high standards of construction (and thereby mitigate hazard), by refusing to provide cover for buildings that do not comply with the set codes.

Hazard insurance can also be used to encourage the adoption of hazard mitigation measures at the community-planning level. Insurance, particularly under a government programme, should be provided only for those communities that have adopted land-use regulations in hazardous areas.

9.7.3 The role of the insurer (and reinsurer) summarised

To summarise, there are a number of ways in which insurers can serve to encourage loss prevention measures aimed at mitigating earthquake (and related) hazards. All depend on the insurer having an accurate impression of the distribution of earthquake hazard and risk in a region. To this end, the techniques and data that have been presented in this and preceeding chapters are of great value to the insurance industry. It is to be hoped that they will enable insurers to play their part, in helping to curb the dramatic escalation of earthquake risk that has been observed in regions like the Middle East in recent years.

9.8 CONCLUSIONS

There are two measures of earthquake risk that are of importance to insurers and reinsurers:

- the risk per insured liability (premium rating);

- the risk of a large number of simultaneous losses stemming from a single earthquake event (accumulation assessment).

The purpose of this chapter has been to show ways in which the data and techniques presented in previous chapters, may be applied to both these aspects of earthquake risk assessment (and control). Most of the discussion has focussed upon the assessment and control of earthquake risk in buildings.

The chapter has served to highlight that an earthquake hazard zonation produced using the R.O.A. scheme (as described in Chapter 7, and applied in Chapter 8), provides an ideal basis for insurance-oriented risk analysis. By combining exposure data taken from such a zonation, with appropriate loss-susceptibility data (as summarised in this chapter), it is possible to determine expected annual earthquake losses for different types of building. These can then be incorporated in premium calculations to derive earthquake ratings that are commensurate with the risk. A method of premium calculation that follows these principles has been summarised in this chapter.

The calculation of earthquake insurance premiums can be simplified by producing standard rate schedules to be used in conjunction with R.O.A. hazard zonations. For a given severity of earthquake hazard, these schedules show the annual basic premium that needs to be charged for different types and heights of construction. To determine a premium rate, all an insurer then needs is information concerning building type and location.

The R.O.A hazard zonation scheme could be extended to earthquake accumulation assessment. This would involve producing standardised grid networks for countries (or even continents). Each grid unit would be used as both an earthquake exposure zone, <u>and</u> an accumulation assessment zone. Through this approach, it would be possible to standardise the entire risk assessment procedure, leading to improved loss accumulation assessments. The technique would also be very amenable to computerisation.

Improved accumulation assessments can only serve to reduce the vulnerability of the insurance industry to catastrophic loss. By taking steps to control its own exposure to earthquake hazard, it is to be hoped that the industry can help stem the dramatic escalation of earthquake risk that has been witnessed in regions like the Middle East.

CHAPTER 10. SUMMARY AND CONCLUSIONS

10.1 INTRODUCTION

This study has provided an analysis of earthquake hazard in the Middle East for insurance and reinsurance purposes. The investigation has involved:

a) Analysis of an actual earthquake disaster (i.e. the 1985 Mexican earthquake), in order that the lessons learned might be applied to the Middle Eastern study;

b) An examination of the reasons for the escalation of earthquake risk that has been witnessed in the Middle East in recent years;

c) A regional analysis of the distribution of earthquake hazard in the Middle East (based on 20th century and historical earthquake data);

d) The development of an insurance-oriented technique of hazard zonation for use in the parts of the region that are exposed to the earthquake threat;

e) The application of the hazard zonation scheme to a Middle Eastern country (i.e. Israel);

f) An examination of the ways in which the data and techniques presented in this study can be used by insurers and reinsurers to control earthquake risk.

The purpose of this final chapter is to summarise the major conclusions of the study. The implications of these are assessed, and some suggestions for possible future research are given. The chapter closes by listing the publications that have arisen from the study so far.

10.2 MAJOR FINDINGS

The major conclusions to be drawn from the study are as follows:

a) The Middle East has a long and continuous history of earthquake disasters. Recent earthquakes in the region have served to confirm that this threat still exists. For example those at Agadir (1960), El Asnam (1980) and Dhamar (1982). The region has experienced very considerable population growth and economic expansion in recent decades. Much of this has been over-concentrated in areas that are exposed to earthquake hazard. As a direct consequence, the vulnerability of many Middle Eastern countries to large earthquake losses (both in human and monetary terms) has increased quite substantially. This is something that is of concern to the insurance industry, which is becoming aware of the need for more precise studies of earthquake hazard in the Middle East.

b) The 1985 Mexican earthquake has served to highlight the dangers associated with the over-concentration of people and economic investment in seismic areas. In addition, it has demonstrated just how vulnerable a modern high-rise urban agglomeration (like Mexico City) can be to a distant earthquake event. This has important implications for earthquake hazard assessment in other parts of the world, including the Middle East. In particular, it demonstrates that hazard and risk assessments now need to consider the threat posed to cities situated many hundreds of kilometres away from the most active seismic belts.

c) A number of other very important lessons have been learned from the Mexican earthquake catastrophe. Foremost amongst these is the identification of several factors that need to be taken into consideration when attempting an analysis of earthquake hazard and risk in a region. These include:

- the control that superficial geology exerts on the severity of ground motion experienced during earthquakes;

- the influence of type and height of construction in controlling the susceptibility of a building to earthquake damage;

- the value of historical earthquake data in delineating the distribution of earthquake hazard. Such data can also help to identify any spatial and temporal patterns that may exist in earthquake activity.

These lessons have been incorporated in the analysis of earthquake hazard in the Middle East.

d) Middle Eastern earthquakes are generated in a variety of seismo-tectonic environments. By analysing the tectonic setting and 20th century seismicity of the region, it has been possible to identify these and to characterise the types of earthquake activity associated with them. The tectonic environments include:

- Zones of plate separation along the Red Sea rift and Azores-Gibraltar ridge (associated with shallow seismicity);

- Zones of plate collision along the Zagros, Taurus and Atlas fold mountains (shallow seismicity);

- Zones of plate transcursion along the Dead Sea, North Anatolian and East Anatolian transform faults (shallow seismicity);

- Zones of plate subduction along the Calabrian, Cretan and Cyprian arcs (shallow to intermediate seismicity).

However, 20th century earthquake data alone cannot be relied upon to give a wholly accurate impression of the distribution of earthquake hazard in the Middle East. This is because the length of time covered by the data is simply too short when compared to the time-scale on which tectonic processes in the region operate. It is for this reason that historical earthquake data need to be incorporated in Middle Eastern earthquake hazard assessments.

e) Analysis of historical earthquake activity in the Middle East is greatly facilitated by the excellent historical record that has been preserved for the region. Advantage of this has been taken by compiling a comprehensive catalogue (and computerised database) of pre-20th century Middle Eastern earthquakes. In addition to highlighting the areas that have been most susceptible to earthquake damage, this catalogue has shown that a number of secondary hazards have occurred in association with earthquakes in the region (e.g. landslides, liquefaction, tsunamis and seiches). These have often served to increase the severity of earthquake impact upon human settlements.

f) By combining the 20th century and historical earthquake data, it has been possible to conduct a detailed regional examination of the distribution of earthquake hazard in the Middle East, using a record of earthquake activity that (for parts of the region) extends back over 4,000 years. This analysis has enabled the areas of greatest earthquake hazard to be identified. These are:

- the coastal margins of the eastern Mediterranean;
- the Levant region;
- the Mesopotamian plains of Iraq, and the Zagros foothills of the northern and eastern parts of the country;
- the margins of the Red Sea, particularly the western side of the Arabian peninsula;
- the Nile delta region of Egypt;
- the northern and littoral regions of Morocco, Algeria, Tunisia and Libya.

Areas of negligible earthquake hazard include:

- the central and eastern parts of the Arabian peninsula;
- south-western and western Iraq;
- eastern Syria and Jordan;
- the Saharan region of Morocco, Algeria and Tunisia.

g) Within the hazardous parts of the region, the risk of large earthquake losses varies according to population density and the amount of economic development that has taken place (or is currently occurring). Earthquake risk is greatest in the following areas:

- the Levant region;
- the Mesopotamian plain and Nile delta;
- the western coastal margin of Saudi Arabia, and the Gulf of Suez;
- the coastal regions of North Africa.

The vulnerability of these areas to large earthquake losses is now greater than ever before. This is due to the increased tendency towards high-rise construction in Middle Eastern cities. The Mexican earthquake served to highlight the fact that medium to high-rise buildings are sensitive to earthquakes over much greater distances than low-rise structures. This is particularly the case if the buildings are situated upon unconsolidated sediments, which tend to have low natural frequencies of vibration corresponding to those of the structures. Geological foundations of this type unfortunately characterise many of the most densely inhabited parts of the Middle East (e.g. the coastal plains, river valleys and delta regions).

h) It is of particular concern to note the very widespread destruction that has accompanied some historical earthquakes in the Middle East. Foremost amongst these are the high magnitude, intermediate-depth shocks that originate in the eastern Mediterranean basin (e.g. along the Cretan and Cyprian arcs). The historical catalogue has shown that these are capable of causing damage along the entire eastern Mediterranean coastline, thereby affecting a number of countries simultaneously. The increased height of construction in many modern Middle Eastern cities, means that distant offshore earthquakes of this type now have even greater potential to cause large loss accumulations over very wide areas.

i) The regional analysis has served to provide evidence of fluctuations in the seismicity of different Middle Eastern countries through time. These are most apparent in the eastern part of the region. The fluctuations may be due (in part) to oscillations in earthquake activity between contiguous tectonic units. In particular, the historical earthquake record would seem to indicate that periods of increased earthquake activity along the Red Sea rift (lasting several centuries) may have alternated with similar periods along the Dead Sea rift and Border zone. There is much stronger evidence to indicate that earthquake activity has oscillated between the latter two zones and the Anatolian fault systems of Turkey. The implication of these suggested patterns of earthquake occurrence is that there is a knock-on effect of seismic activity between the tectonic units. This can possibly be taken to explain the lull in seismicity observed along the Dead Sea fault system this century (especially in Syria), in contrast to the activity observed in the Red Sea region.

j) In the light of the regional examination of earthquake hazard in the Middle East, a technique of hazard zonation has been developed for application in the areas that are exposed to the earthquake threat. This technique (the R.O.A scheme) is designed to meet the specific requirements of insurers and reinsurers, in that it provides an assessment in probabilistic terms and uses intensity as the zoning parameter. By taking into consideration the influence that surficial geology exerts on the severity of earthquake hazard, the technique also incorporates an important lesson learned from the 1985 Mexican earthquake.

k) The usefulness and applicability of the R.O.A. zonation scheme has been demonstrated by employing it to produce a hazard zonation of Israel. This zonation serves to delineate the areas of greatest earthquake hazard with considerable accuracy, and is a marked improvement upon any previous attempts to zone the country for insurance purposes. Using Israel as a case-study, it has been shown how such a zonation can form the basis of an insurance-oriented analysis of earthquake hazard and risk in a country. In addition, large-scale hazard maps of some Israeli cities have been produced, in order to demonstrate how the hazard zonation process can be taken a stage further from the national classifications produced using the R.O.A scheme.

l) A hazard zonation produced according to the R.O.A. scheme can easily be incorporated in standard insurance and reinsurance procedures aimed at controlling earthquake risk. By combining exposure data taken from such a zonation with appropriate loss-susceptibility data, it is possible to derive accurate earthquake premiums (ratings) that are commensurate with the risk. The entire earthquake rating procedure can be simplified by producing standard rate schedules to be used in conjunction with R.O.A. hazard zonations. For a given severity of earthquake hazard, these show the annual basic premium that needs to be charged for different types and heights of construction.

m) The R.O.A hazard zonation scheme could also be extended for use by insurers and reinsurers in earthquake accumulation assessments. It would provide a means of standardising the entire risk assessment procedure, and would be very amenable to computerisation.

Improved earthquake hazard and risk assessments can only serve to reduce the vulnerability of the insurance industry to catastrophic loss. By taking steps to control their own exposure to earthquake hazard, it is to be hoped that insurers and reinsurers can help to stem the escalation of earthquake risk that has recently been witnessed in regions like the Middle East.

10.3 THE CONTRIBUTION TO KNOWLEDGE

The major contributions of this study to knowledge are as follows:

a) The study provides the first detailed analysis of earthquake hazard and risk in the Middle East for insurance and reinsurance purposes;

b) An in-depth analysis of a major earthquake disaster has been presented, and the implications of this for earthquake hazard and risk assessment in other parts of the world examined;

c) A comprehensive catalogue of historical earthquake activity in the Middle East has been compiled, and the data displayed cartographically;

d) A technique of earthquake hazard zonation has been developed that will enable the production of more accurate zonations than those currently available to insurers and reinsurers;

e) A detailed (insurance-oriented) analysis of earthquake hazard and risk in Israel has been presented, based on a new, improved earthquake hazard zonation of the country;

f) Ways of improving existing insurance and reinsurance procedures for controlling earthquake risk have been examined, and some possible new approaches to the problem discussed.

10.4 SUGGESTIONS FOR FURTHER RESEARCH

There are a number of important ways in which the work presented in this study could be extended:

a) The historical earthquake catalogue listed in Appendices A and B is more comprehensive than any other previously available for the Middle East. It should serve as a sound basis for further detailed investigation concerning historical aspects of seismicity in the region. This will probably require the examination of ancient archives and manuscripts;

b) The suggested patterns of fluctuating seismicity between contiguous tectonic units in parts of the Middle East clearly require further analysis. This would probably involve a more thorough examination of the historical seismicity of the areas in question;

c) The R.O.A. zonation scheme should be applied to all Middle Eastern countries that are exposed to the earthquake hazard. By comparing the resultant zonations with the data contained in the historical catalogue, it should be possible to test the validity of the scheme more fully;

d) An obvious progression from this study would be the development of a computerised procedure for earthquake risk assessment, based on the grid approach to hazard zonation employed by the R.O.A. scheme. This could encompass both premium rating and accumulation assessment aspects of risk evaluation and control.

10.5 PUBLICATIONS ARISING FROM THE STUDY

The following publications have arisen from the study so far:

BOOTH, E.D.; PAPPIN, J.W.; MILLS, J.H.; DEGG, M.R. and STEEDMAN, R.S. (1986), The Mexican earthquake of 19 September 1985, a field report by EEFIT, London: the Society for Earthquakes and Civil Engineering Dynamics, 150pp.;

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APPENDICES

The pages of the appendices are copied back to back. The page numbers of Appendix A (Part I of the catalogue of historical earthquakes) are preceded by the letter "A", and those of Appendix B (Part II of the catalogue) by "B".

The catalogue has been printed from a number of BBC microcomputer data base files. Its format is discussed in Section 5.4.

APPENDIX A1

THE HISTORICAL CATALOGUE (PART I)

1.

DATE	BC 2600
FELT IN	ISRAEL
DETAILS	WIDESPREAD DESTRUCTION NORTH OF THE DEAD SEA
SOURCE	15

2.

DATE	BC 2600
FELT IN	SYRIA
DETAILS	DESTRUCTION OF EBLA (TEL MARDIKH), 50 km SOUTH EAST OF ALEPPO
SOURCE	15

3.

DATE	BC 2200
EPICENT.	TELL BASTA REGION, EGYPT
INTENS.	8
MAG.	5.8
FELT IN	EGYPT
DETAILS	AFFECTED SHARQIYA PROVINCE IN THE NILE DELTA FELT IN ABU HAMMAD. FELT OVER AN AREA OF 25,000 sq km
HAZARDS	DEEP FISSURE AT TELL BASTA
SOURCE	21,28

4.

DATE	BC 2150 +/- 100
EPICENT.	ISRAEL
FAULT	DEAD SEA
FELT IN	ISRAEL
DETAILS	DESTRUCTION OF SODOM & GOMMORAH
SOURCE	12

5.

DATE	BC 1560
FELT IN	ISRAEL
DETAILS	JERICHO AFFECTED
SOURCE	19

6.

DATE	BC 1500
DETAILS	VOLCANIC ERUPTION AT SANTORINI (THERA) ISLAND IN THE AEGEAN SEA. MANY DEAD. POSSIBLY DESTROYED THE MINOAN CIVILIZATION ON CRETE
SOURCE	38,39,40

7.

DATE	BC 1470
FELT IN	ISRAEL
DETAILS	FELT IN SINAI DESERT AT CADES-VARNI (RITHMA)
SOURCE	19

8.

DATE	BC 1356 or 1365
FELT IN	SYRIA
DETAILS	AFFECTED RAS SHAMRA
HAZARDS	A TSUNAMI DESTROYED UGARIT ON THE SYRIAN COAST
SOURCE	12,22

9.

DATE	BC 1260
FELT IN	IRAQ
DETAILS	FELT IN BABYLON
SOURCE	18

10.

DATE	BC 1250 ca
FAULT	DEAD SEA
FELT IN	ISRAEL, JORDAN
DETAILS	DESTRUCTION OF JERICHO, TEL DEIR ALLA & OTHER CITIES
HAZARDS	THE JORDAN RIVER WAS CUT-OFF AT DAMIYA BY LANDSLIDES OF THE LISAN MARL
SOURCE	12

11.

DATE	BC 1050 ca
EPICENT.	NEAR TIMNA, SINAI
FAULT	ARAVA
MAG.	ML 6.2
FELT IN	SINAI
DETAILS	DESTRUCTION OF TIMNA COPPER MINES
SOURCE	12

12.

DATE	BC 900
FELT IN	ISRAEL, JORDAN
DETAILS	FELT IN PALESTINE
SOURCE	19

13.

DATE	BC 900
FELT IN	ISRAEL
DETAILS	FELT IN SINAI DESERT ESPECIALLY AT MOUNT SINAI
SOURCE	19
COMMENT	SAME AS 12?

14.

DATE	BC 880
FELT IN	ISRAEL, JORDAN
DETAILS	FELT IN PALESTINE
SOURCE	19

15.

DATE	BC 854
EPICENT.	NEAR SEA OF GALILEE (LAKE TIBERIAS), JORDAN
FAULT	DEAD SEA
MAG.	ML 6.6
FELT IN	ISRAEL, JORDAN
DETAILS	DESTRUCTION OF APHEKA ON THE EASTERN SHORE OF THE LAKE
SOURCE	12

16.

DATE	BC 783
FELT IN	ISRAEL, JORDAN
DETAILS	FELT BOTH SIDES OF THE JORDAN RIVER. VERY STRONG IN JERUSALEM
SOURCE	19

17.

DATE	BC 760 ca
FELT IN	ISRAEL, LEBANON
DETAILS	NO EARTHQUAKE DAMAGE DESCRIBED
HAZARDS	TSUNAMI ON THE COASTS OF ISRAEL & LEBANON
SOURCE	22

18.
DATE BC 759 Oct 7
EPICENT. EAST OF HAZOR, ISRAEL
FAULT DEAD SEA
INTENS. 11
FELT IN ISRAEL, EGYPT, IRAQ
DETAILS GREAT DESTRUCTION IN JUDAEA, SAMARIA & GALILEE. INTENSITY AT JERSUALEM =8. DESTRUCTION OF HAZOR & KINNERET (9 km SOUTH OF TIBERIAS). FELT IN MESOPOTAMIA & EGYPT
HAZARDS SEICHE IN THE SEA OF GALILEE. LANDSLIDE IN THE KIDRON VALLEY OF JERUSALEM
SOURCE 12

19.
DATE BC 600
FELT IN IRAQ
DETAILS FELT IN SINKARAH WHERE THE TEMPLE OF TARAS WAS DESTROYED
SOURCE 5,18

20.
DATE BC 592
FELT IN IRAQ
DETAILS FELT ALONG THE KEBAR RIVER (GREAT ZAB RIVER)
SOURCE 5,18

21.
DATE BC 590
EPICENT. OFF COAST OF SUR (TYRE), LEBANON
INTENS. 9-10
MAG. ML 6.8
FELT IN LEBANON
DETAILS FLOODING AT TYRE
HAZARDS TSUNAMI ALONG THE LEBANESE COAST
SOURCE 12,22

22.
DATE BC 525
EPICENT. OFF COAST OF SUR (TYRE), LEBANON
INTENS. 11
MAG. ML 7.5
FELT IN LEBANON
DETAILS TYRE DESTROYED & SIDON WAS GREATLY DAMAGED
HAZARDS TSUNAMI ALONG THE LEBANESE COAST
SOURCE 12,22

23.
DATE BC 435
FAULT DEAD SEA
FELT IN ISRAEL
SOURCE 12

24.
DATE BC 221
EPICENT. SIWA OASIS, EGYPT
INTENS. 8
FELT IN EGYPT, LIBYA
DETAILS AFFECTED SIWA OASIS IN THE WESTERN DESERT. FELT OVER 100,000 sq km IN WESTERN EGYPT & LIBYA
SOURCE 28

25.
DATE BC 216
FELT IN RHODES, CYPRUS & SYRIA
DETAILS NONE AVAILABLE
SOURCE 19
COMMENT (31) CITES BC 225 AS THE DATE FOR AN EARTHQUAKE IN RHODES CAUSING SEVERE DAMAGE

26.
DATE BC 184
EPICENT. NEAR ANTIOCH
FAULT NORTH LEVANT
MAG. ML 6.8
FELT IN SYRIA
SOURCE 12

27.
DATE BC 146 to 138
FELT IN SYRIA, PHOENECIA (SYRIA/LEBANON), ISRAEL
SOURCE 19

28.
DATE BC 140 +/- 2
EPICENT. OFF COAST SUR (TYRE), LEBANON
INTENS. 10
MAG. ML 7.0
FELT IN LEBANON, ISRAEL, CYPRUS
DETAILS STRONG IN CYPRUS. (22) CITES THE DATE AS BC 138
HAZARDS TSUNAMI BETWEEN ACRE & TYRE. PARTIAL SUBSIDENCE OF SUR ISLAND
SOURCE 12,22

29.
DATE BC 92 Feb 28
EPICENT. SOUTH EAST OF CYPRUS
MAG. ML 7.1
FELT IN CYPRUS, SYRIA, EGYPT, ISRAEL
DETAILS NO EARTHQUAKE DAMAGE DESCRIBED
HAZARDS A LARGE TSUNAMI HIT COASTAL CITIES OF THE LEVANT
SOURCE 12

30.
DATE BC 91
FAULT NORTH LEVANT
SOURCE 12

31.
DATE BC 63 or 64
FAULT NORTH LEVANT (NORTHERN PART)
MAG. ML 7.7
FELT IN SYRIA & ISRAEL
DETAILS DESTRUCTION OF ANTIOCH. DAMAGE TO TEMPLE WALLS IN JERUSALEM. INTENSITY IN ISRAEL =6-7
SOURCE 6,9,12,19,30

32.
DATE BC 37 or 36
FAULT NORTH LEVANT
FELT IN SYRIA
DETAILS FELT AT ANTIOCH
SOURCE 12,19

33.

DATE	BC 33 or 32
FELT IN	ISRAEL
DETAILS	30,000 DEAD
SOURCE	19
COMMENT	SAME AS 34?

34.

DATE	BC 31 (or 30) Sep 2
EPICENT.	NORTH OF THE DEAD SEA, ISRAEL
FAULT	DEAD SEA
MAG.	ML 7.0
FELT IN	ISRAEL & JORDAN
DETAILS	SEVERE IN GALILEE. ALSO AFFECTED JERICHO & THE WEST BANK OF THE DEAD SEA. FELT IN JERUSALEM. THOUSANDS OF PEOPLE WERE KILLED. INTENSITY IN ISRAEL =8 OR ABOVE
HAZARDS	30cm SHEAR ALONG THE KHIRBET KUMRAN FAULT TO THE NORTH OF THE DEAD SEA. THE FAULT HAS NOT MOVED SINCE
SOURCE	6,7,9,12,19,29,30

35.

DATE	BC 23 +/- 3
EPICENT.	OFF COAST OF PAPHOS, CYPRUS
INTENS.	10-11
MAG.	7.3
FELT IN	EGYPT , ISRAEL, CYPRUS
DETAILS	AFFECTED NORTH EGYPT. THE TEMPLES OF THEBES (UPPER EGYPT) WERE DESTROYED
HAZARDS	PELUSIUM WAS FLOODED TO A GREAT DEPTH BY A TSUNAMI WHICH AFFECTED THE NILE DELTA
SOURCE	6,12,19,20,21,22
COMMENT	EXACT DATE UNCERTAIN. (21) INCORRECTLY GIVES THE EPICENTRE AS OFF THE COAST OF ALEXANDRIA. ACCORDING TO (31), AN EXTRA EVENT AFFECTED SALAMIS, CYPRUS IN BC 15

36.

DATE	BC 9 to AD 50
FAULT	ARAVA
MAG.	ML 6.2
FELT IN	ISRAEL, JORDAN
DETAILS	FELT IN ARAM, EILAT & PETRA (JORDAN)
SOURCE	12
COMMENT	DATE POSSIBLY AD 48

37.

DATE	AD 19
EPICENT.	POSSIBLY NEAR SIDON, LEBANON
FELT IN	LEBANON, ASIA MINOR, SYRIA, ISRAEL
DETAILS	ESPECIALLLY AFFECTED SIDON
SOURCE	19
COMMENT	ACCORDING TO (31) AND (38) A SEVERE EVENT OCCURRED IN TURKEY IN AD 17 (EPICENTRAL INTENSITY =10)

38.

DATE	AD 30
FELT IN	ISRAEL
DETAILS	AFFECTED JUDAEA. SLIGHT IN JERUSALEM
SOURCE	6,19

39.

DATE	AD 33
FELT IN	ISRAEL, ASIA MINOR
DETAILS	FELT IN JUDAEA. SLIGHT IN JERUSALEM
SOURCE	6,13
COMMENT	SAME AS 38?

40.

DATE	AD 37
FELT IN	SYRIA, TURKEY
DETAILS	FELT IN ANTIOCH
SOURCE	6

41.

DATE	AD 48
FAULT	ARAVA
MAG.	6.2
FELT IN	ISRAEL
DETAILS	MODERATE IN JERUSALEM
SOURCE	6,12

42.

DATE	AD 52 or 53
FAULT	NORTH LEVANT
MAG.	6.6
FELT IN	SYRIA
DETAILS	INTENSITY AT ANTIOCH =8-9
SOURCE	3,12

43.

DATE	AD 65
FELT IN	ASIA MINOR, SYRIA, ISRAEL
DETAILS	FELT IN JERUSALEM
SOURCE	19

44.

DATE	AD 76
EPICENT.	OFF CYPRUS ?
INTENS.	10
MAG.	ML 7.0
FELT IN	NORTH WEST SYRIA
DETAILS	NO ACTUAL DESCRIPTIONS OF EARTHQUAKE DAMAGE
SOURCE	6,12,19,22
	COMMENT (22) STATES THAT THIS EVENT IS DOUBTFUL, & PROBABLY STEMS FROM REPORTS OF A STORM SEA WAVE OF THE TYPE COMMON OFF CYPRUS (38) AN EVENT THAT AFFECTED CYPRUS IN AD 77 or 78

45.

DATE	AD 82
FAULT	NORTH LEVANT
MAG.	6.6
SOURCE	12
COMMENT	DOUBTFUL EVENT

46.

DATE	AD 93
EPICENT.	THRACE, GREECE
FELT IN	EGYPT
DETAILS	SEVERE EVENT WITH MANY DEATHS AT HELLESPONT
SOURCE	20,31

47.

DATE	AD 94
FAULT	NORTH LEVANT
MAG.	6.1
SOURCE	12
COMMENT	DOUBTFUL EVENT

48.

DATE	AD 115 Dec 13
EPICENT.	NEAR SAMANDAG, TURKEY
FAULT	NORTH LEVANT
MAG.	ML 7.4
FELT IN	SYRIA, ISRAEL
DETAILS	ANTIOCH DESTROYED WITH INTENSITY =10-11. A TOTAL OF 260,000 DEAD
HAZARDS	TSUNAMI AFFECTING YAVNE & CAESARIA IN ISRAEL
SOURCE	3,12
COMMENT	(38) CITES AN EVENT IN AD 109 or 110 THAT AFFECTED ANTIOCH

49.

DATE	AD 128
FELT IN	SYRIA, ANATOLIA (TURKEY), JORDAN, ISRAEL
DETAILS	STRONG EARTHQUAKE AFFECTING CAESARIA & LYDDA (LOD)
SOURCE	6,7,9,19

50.

DATE	AD 130
FAULT	BEKA'A
MAG.	ML 6.1
FELT IN	SYRIA, ISRAEL
DETAILS	STRONG IN DAMASK (DAMASCUS). INTENSITY IN ISRAEL =6-7
SOURCE	12,30
COMMENT	SAME AS 50?

51.

DATE	AD 233
FAULT	DEAD SEA
MAG.	ML 6.3
FELT IN	SYRIA
DETAILS	DAMAGE IN DAMASK (DAMASCUS)
SOURCE	12

52.

DATE	AD 245
FAULT	NORTH LEVANT
MAG.	ML 7.5
FELT IN	SYRIA
DETAILS	AFFECTED ANTIOCH
SOURCE	12

53.

DATE	AD 272
FAULT	NORTH LEVANT
MAG.	ML 6.2
SOURCE	12

54.

DATE	AD 306 winter
FELT IN	ISRAEL, LEBANON
DETAILS	A STRONG & DESTRUCTIVE EARTHQUAKE AFFECTING TYRE, SIDON, JERUSALEM & CAESAREA. INTENSITY IN ISRAEL =6-7
HAZARDS	TSUNAMI AT CAESAREA, ISRAEL
SOURCE	7,9,12,30

55.

DATE	AD 312
FELT IN	EGYPT
DETAILS	IN ALEXANDRIA MANY HOUSES WERE DAMAGED AND MANY PEOPLE INJURED
SOURCE	20
COMMENT	SIMILAR TO THE DESCRIPTION OF AN EVENT IN AD 328

56.

DATE	AD 315
FELT IN	ISRAEL ?
DETAILS	NO EARTHQUAKE REPORTS
HAZARDS	SEICHE IN THE DEAD SEA
SOURCE	7,22
COMMENT	POSSIBLY A LOCAL EARTHQUAKE ON THE DEAD SEA FAULT

57.

DATE	AD 320
EPICENT.	OFF ALEXANDRIA, EGYPT
INTENS.	7
MAG.	5.9
FELT IN	EGYPT
DETAILS	GREAT DAMAGE AND HEAVY CASUALTIES IN ALEXANDRIA
SOURCE	12,21

58.

DATE	AD 330
EPICENT.	NEAR CYPRUS
INTENS.	9
MAG.	ML 6.4
FELT IN	SYRIA & TURKEY
DETAILS	AFFECTED ANTIOCH
SOURCE	12

59.

DATE	AD 333
FELT IN	SYRIA
SOURCE	19
COMMENT	SAME AS 60?

60.

DATE	AD 334
FAULT	NORTH LEVANT
MAG.	ML 7.0
FELT IN	SYRIA & ALL OVER NEAR EAST
DETAILS	DESTRUCTION OF ANTIOCH
SOURCE	12

61.

DATE	AD 340
FELT IN	SYRIA, ASIA MINOR
DETAILS	INTENSITY AT ANTIOCH =9
SOURCE	3,19

62.

DATE	AD 341
FAULT	NORTH LEVANT
MAG.	6.2
FELT IN	SYRIA
DETAILS	AFFECTED ANTIOCH
SOURCE	12,19
COMMENT	SAME AS ABOVE ?

63.

DATE	AD 342/343
FELT IN	NEAR EAST, SYRIA
DETAILS	FELT ESPECIALLLY AT ANTIOCH. 40,000 DEAD
SOURCE	19,31,38
COMMENT	(22) RECORDS AN EARTHQUAKE AT FAMAGUSTA, CYPRUS IN AD 342

64.

DATE	AD 344
EPICENT.	RHODES (38.0°N 24.0°E)
FELT IN	NEAR EAST, SYRIA
DETAILS	FELT ESPECIALLY AT ANTIOCH. AN EXTREME EVENT WHICH AFFECTED DIRES AND CAMPANIA IN ITALY
HAZARDS	TSUNAMI IN DARDANELLES, NIKSAN & THRACIAN COAST
SOURCE	6,22,31

65.

DATE	AD 348/349
EPICENT.	OFF COAST BEIRUT, LEBANON
INTENS.	10
MAG.	ML 7.0
FELT IN	LEBANON, SYRIA
DETAILS	DESTRUCTION OF BEIRUT. ALSO AFFECTED THE SYRIAN COAST & THE ARWAD ISLANDS
HAZARDS	TSUNAMI
SOURCE	12,19,22

66.

DATE	AD 358 Aug 24
FELT IN	GREECE, TURKEY, SYRIA, EGYPT
DETAILS	AFFECTED MACEDONIA IN GREECE & BITHYNIA IN ANATOLIA. SEVERE AT NICOMEDIA (IZMIT) IN TURKEY
HAZARDS	TSUNAMI AT ALEXANDRIA, EGYPT
SOURCE	20,31

67.

DATE	AD 362 May 24
FAULT	DEAD SEA
MAG.	ML 6.4
FELT IN	ISRAEL, JORDAN
DETAILS	AFFECTED THE DEAD SEA ESPECIALLY THE JORDANIAN COASTLINE. ALSO AFFECTED JERUSALEM, BEYT GUVRAN, GAZA, NABLUS & EL-KERAK
HAZARDS	SEICHE IN THE DEAD SEA
SOURCE	6,12,22

68.

DATE	AD 365 Jul 21
EPICENT.	NEAR KNOSSOS, SOUTH WEST CRETE (35.3^{O}N 25.2^{O}E)
INTENS.	10-11
MAG.	ML 7.7
FELT IN	ISRAEL, EGYPT, LIBYA, SICILY, GREECE
DETAILS	50,000 PEOPLE WERE KILLED IN A GREAT EARTHQUAKE WHICH CAUSED MUCH DAMAGE AT ALEXANDRIA
HAZARDS	TSUNAMI IN THE EASTERN MEDITERRANEAN AFFECTING EGYPT, LIBYA & SICILY
SOURCE	12,19,20,22,23,31

69.

DATE	AD 367 Oct 11
EPICENT.	NEAR CYPRUS
INTENS.	9-10
MAG.	ML 6.7
FELT IN	ISRAEL, TURKEY, LIBYA, SICILY
DETAILS	THOUSANDS DEAD. A SEVERE EVENT WHICH AFFECTED NICAEA, TURKEY
SOURCE	12,31

70.

DATE	AD 387
FAULT	NORTH LEVANT
MAG.	6.1
FELT IN	SYRIA
DETAILS	AFFECTED ANTIOCH
SOURCE	12,19

71.	
DATE	AD 394
FELT IN	ISRAEL & SYRIA
DETAILS	INTENSITY AT ANTIOCH =9
SOURCE	3,19
COMMENT	SAME AS 72?

72.	
DATE	AD 396
FAULT	NORTH LEVANT
MAG.	6.3
FELT IN	ISRAEL, SYRIA, ASIA MINOR
DETAILS	INTENSITY AT ANTIOCH =9. ISKENDERUN SUFFERED CONSIDERABLY IN THE EATHQUAKE WHICH AFFECTED ASIA MINOR PRINCIPALLY
SOURCE	3,19,20

73.	
DATE	AD 419
EPICENT.	31.5N 35.0E
FAULT	DEAD SEA
MAG.	ML 6.2
FELT IN	ISRAEL
DETAILS	MANY TOWNS & VILLAGES DESTROYED IN PALESTINE. DESTRUCTION OF KIRBET-SHAMA & APHEK. FELT IN JERUSALEM. INTENSITY IN ISRAEL =6-7
SOURCE	6,9,12,13,30,31,38

74.	
DATE	AD 447 Dec 8
EPICENT.	NORTH WEST TURKEY ?
FAULT	NORTH ANATOLIAN ?
MAG.	ML 7.5
FELT IN	ASIA MINOR, ISRAEL, EGYPT, SYRIA
DETAILS	A MAJOR EARTHQUAKE. VERY STRONG IN JERUSALEM ? FELT IN ALEXANDRIA & ANTIOCH. INTENSITY IN ISRAEL =8 OR ABOVE
HAZARDS	A TSUNAMI AFFECTED THE MARMARA SEA, CONSTANTINOPLE & THE DARDANELLES ON THIS DATE
SOURCE	6,7,9,12,19,22,30

75.
DATE AD 457 or 458 Sep
FAULT NORTH LEVANT
MAG. 6.5
FELT IN SYRIA
DETAILS COMPLETE DESTRUCTION OF ANTIOCH. 80,000 DEAD
SOURCE 3,12,19

76.
DATE AD 494
FELT IN ASIA MINOR, SYRIA, LEBANON
DETAILS STRONG. AFFECTED TRIPOLI
SOURCE 13,19,38

77.
DATE AD 498 Sep
FELT IN JORDAN, ISRAEL
DETAILS SEVERE AT IMWAS. MANY DEAD. INTENSITY IN ISRAEL =8 OR ABOVE
SOURCE 6,30

78.
DATE AD 500
FAULT NORTH LEVANT
INTENS. 11
MAG. ML 7.5
FELT IN ASIA MINOR, SYRIA, GREECE, ISRAEL
DETAILS DESTRUCTION OF ANTIOCH. DAMAGE AT SAFED
SOURCE 12,19

79.
DATE AD 502 Aug 19 or 21
EPICENT. OFF COAST ACRE, ISRAEL
INTENS. 10
MAG. ML 7.0
FELT IN ISRAEL, JORDAN, LEBANON
DETAILS A MAJOR EARTHQUAKE WHICH DESTROYED ACRE. SEVERE IN TYRE & SIDON, SLIGHT DAMAGE IN BEIRUT & BYBLOS (JUBEIL). INTENSITY IN ISRAEL =8 OR ABOVE
SOURCE 6,7,9,12,30

80.

DATE	AD 525 May 29
EPICENT.	OFF COAST SIDON, LEBANON
INTENS.	9-10
MAG.	ML 6.7
SOURCE	12
COMMENT	NO DETAILS CONCERNING THIS EVENT - SAME AS 81?

81.

DATE	AD 526 May 29
FAULT	NORTH LEVANT
MAG.	6.5
FELT IN	SYRIA, POSSIBLY ISRAEL
DETAILS	INTENSITY AT ANTIOCH =9-10. 250,000 DEAD
SOURCE	3,12,27
COMMENT	(31) CITES DATE AS 527

82.

DATE	AD 528 Nov 29
FAULT	NORTH LEVANT
MAG.	6.9
FELT IN	SYRIA, ASIA MINOR, IRAQ, ISRAEL, EGYPT, LEBANON
DETAILS	INTENSITY AT ANTIOCH =10-11. DAMAGE IN DAMASCUS & JERUSALEM. AFFECTED BEIRUT. 5,000 DEAD
HAZARDS	LANDSLIDE INTO THE EUPHRATES AT QULUDHYA, IRAQ
SOURCE	1,3,12,13,31,38

83.

DATE	AD 551 Jul 9
EPICENT.	OFF COAST BEIRUT, LEBANON (33.9^{0}N 35.5^{0}E)
INTENS.	11-12
MAG.	ML 7.8
FELT IN	LEBANON, EGYPT, IRAQ, ARABIA, ISRAEL, MAGHREB, GREECE
DETAILS	A SEVERE EVENT WHICH DESTROYED BEIRUT. DESTRUCTION AT TYRE, SIDON, TRIPOLI & GALILEE. AFFECTED MESOPOTAMIA. MANY THOUSANDS DEAD. INTENSITY IN ISRAEL =8 OR ABOVE
HAZARDS	TSUNAMI ON LEBANESE COAST
SOURCE	5,6,7,9,12,30

84.
DATE AD 553
FAULT NORTH LEVANT
MAG. 6.1
SOURCE 12
COMMENT NO DETAILS CONCERNING THIS EVENT

85.
DATE AD 553
EPICENT. OFF SHORE ALEXANDRIA, EGYPT
INTENS. 5
MAG. 4.8
FELT IN EGYPT
SOURCE 21

86.
DATE AD 554 Aug 15
EPICENT. NEAR RHODES
INTENS. 11
MAG. ML 7.4
FELT IN SYRIA, ISRAEL, IRAQ, LEBANON, GREECE, TURKEY
DETAILS VERY LARGE AREA SHAKEN. AFFECTED ANTIOCH & ITS ENVIRONS & MESOPOTAMIA. ALSO BEIRUT
HAZARDS TSUNAMI AFFECTED MANDALAYA BAY, KOS & SPORADES ISLANDS
SOURCE 5,6,12,19,22

87.
DATE AD 557
FELT IN SYRIA
DETAILS ANTIOCH SEVERELY DAMAGED. ACCORDING TO (31), EARTHQUAKES OCCURRED IN THE ISTANBUL REGION ON 6 Oct AND 14 Dec OF THIS YEAR
SOURCE 19

88.
DATE AD 560
FELT IN LEBANON & TURKEY
DETAILS AFFECTED BEIRUT & CONSTANTINOPLE
SOURCE 19
COMMENT DUE TO MORE THAN 1 EVENT ?

89.

DATE	AD 565
FAULT	BEKA'A
MAG.	ML 6.7
FELT IN	LEBANON, ISRAEL, IRAQ, SYRIA
DETAILS	STRONG IN DAMASK (DAMASCUS), ANTIOCH & BA'ALBEK. FELT IN ISRAEL & IRAQ. 30,000 DEAD
SOURCE	12,38

90.

DATE	AD 579
FAULT	NORTH LEVANT
MAG.	6.1
FELT IN	SYRIA
DETAILS	AFFECTED ANTIOCH & DAPHNE. SEVERE EVENT
SOURCE	12,19,31
COMMENT	DAPHNAE (EGYPT) OR (DAFNA) ISRAEL?

91.

DATE	AD 580
FELT IN	ISRAEL
SOURCE	6,19

92.

DATE	AD 581
FELT IN	SYRIA
DETAILS	INTENSITY AT ANTIOCH =8-9
SOURCE	3

93.

DATE	AD 583
FELT IN	ISRAEL, SYRIA, IRAQ, GREECE
DETAILS	AFFECTED MESOPOTAMIA
SOURCE	5,6,7

94.

DATE	AD 588 Oct 31
FAULT	NORTH LEVANT
MAG.	6.5
FELT IN	SYRIA
DETAILS	VERY DESTRUCTIVE. INTENSITY AT ANTIOCH =9. 60,000 DEAD
SOURCE	3,12,19,27
COMMENT	(12) & (19) CITE THE DATE AS 30/9/587

95.
DATE AD 592
FELT IN ISRAEL ?
DETAILS GEOLOGICAL EVIDENCE FOR AN EARTHQUAKE ALONG THE DEAD SEA FAULT. NO ACTUAL DAMAGE REPORTS
SOURCE 7
COMMENT UNCERTAINTY CONCERNING THIS EVENT

96.
DATE AD 627
FELT IN ARABIA
DETAILS AFFECTED MEDINA
SOURCE 1

97.
DATE AD 628-629
FELT IN ARABIA
DETAILS AFFECTED HIJAZ
SOURCE 2
COMMENT SAME AS ABOVE ?

98.
DATE AD 631-632
FELT IN ISRAEL
DETAILS FELT FOR 30 DAYS
SOURCE 6,19
COMMENT AD 631 ACCORDING TO (19)

99.
DATE AD 634
FELT IN SYRIA
DETAILS INTENSITY AT ALEPPO =8
SOURCE 1,3

100.
DATE AD 637
FELT IN ISRAEL & SYRIA
DETAILS FELT IN JUDAEA
SOURCE 6,19

101.
DATE AD 641
FELT IN SYRIA & ISRAEL
DETAILS FELT IN JUDAEA
SOURCE 6,19
COMMENT SAME AS 100?

102.
DATE AD 641
FELT IN ARABIA
DETAILS AFFECTED WESTERN SAUDI ARABIA, ESPECIALLY MEDINA. A VOLCANIC ERUPTION OCCURRED IN NORTH WEST ARABIA IN AD 640, ACCORDING TO (36) AND (40)
SOURCE 1,2

103.
DATE AD 645
FELT IN YEMEN A.R. & ARABIA
DETAILS AFFECTED WESTERN SAUDI ARABIA
SOURCE 1

104.
DATE AD 658 Jun
EPICENT. NORTH ISRAEL
FAULT DEAD SEA
MAG. ML 6.6
FELT IN ISRAEL, SYRIA, ASIA MINOR
DETAILS STRONG EARTHQUAKE. EXTENSIVE DAMAGE IN NORTH ISRAEL ESPECIALLY AT REHOVOT. INTENSITY IN ISRAEL =6-7
SOURCE 6,9,12,13,19,30

105.
DATE AD 659
FAULT DEAD SEA
MAG. 6.1
FELT IN ISRAEL, JORDAN
DETAILS STRONG AT JERICHO. ALSO AFFECTED KHAN-EL-AHMAR. INTENSITY IN ISRAEL =6-7
SOURCE 6,9,7,12,30

106.
DATE AD 672
FELT IN ISRAEL
DETAILS STRONG AT GAZA, ASCALON & RAMLE. INTENSITY IN ISRAEL =6-7
SOURCE 6,9,30

107.
DATE AD 678
FELT IN IRAQ
DETAILS AFFECTED JAZIRAH. HEAVY DAMAGE BETWEEN RIVERS TIGRIS & THARTHAR
SOURCE 5

108.
DATE AD 710
FELT IN ISRAEL
DETAILS SLIGHT DAMAGE IN JERUSALEM
SOURCE 6,7

109.
DATE AD 712
FELT IN SYRIA
SOURCE 19,24

110.
DATE AD 713 Feb 28
FAULT NORTH LEVANT
MAG. ML 7.0
FELT IN SYRIA, EGYPT, ASIA MINOR
DETAILS INTENSITY AT ANTIOCH =9. ANTIOCH COMPLETELY DESTROYED ACCORDING TO SOME REPORTS. LASTED 40 DAYS
SOURCE 1,3,12,13,19,31
COMMENT (31) CITES THE DATE AS Mar 20

111.
DATE AD 716/717
EPICENT. SYRIA
FAULT NORTH LEVANT
MAG. 6.1
FELT IN SYRIA
DETAILS AFFECTED ANTIOCH CAUSING MODERATE DAMAGE
SOURCE 2,12,24,31

112.
DATE AD 738 Jan 16
FELT IN ISRAEL?
DETAILS STRONG EARTHQUAKE. INTENSITY IN ISRAEL =6-7
SOURCE 9,13,30
COMMENT UNCERTAIN EVENT

113.
DATE AD 742
FELT IN EGYPT, ARABIA, YEMEN A.R.
DETAILS EGYPT - AFFECTED SOUTH SUEZ. FELT OVER A LIMITED AREA. MAXIMUM INTENSITY =6 AT AIN SOUKHNA (CRACKED GROUND). AFFECTED DESERT OF SABA IN ARABIA
HAZARDS LANDSLIDES IN YEMEN
SOURCE 4,13,28,31

114.
DATE AD 742
EPICENT. 35.0°N 38.0°E (APPROX)
FELT IN SYRIA, ISRAEL, ASIA MINOR
DETAILS SEVERE EVENT. MANY DEAD
SOURCE 19,31

115.
DATE AD 746 Jan 18
EPICENT. NORTH OF THE DEAD SEA, ISRAEL (32.ON 35.5E)
FAULT JERICHO FAULT
INTENS. 11
MAG. ML 7.3
FELT IN ISRAEL, JORDAN, EGYPT, ARABIA, SYRIA, IRAQ
DETAILS INTENSITY AT JERUSALEM =9. SEVERE DAMAGE IN TIBERIAS, JERICHO & JERASH. ALSO AFFECTED LOD. DESTRUCTION OF 600 SETTLEMENTS IN JUDAEA, SAMARIA & GALILEE. AFFECTED MESOPOTAMIA. INTENSITY IN ISRAEL >8. TENS OF THOUSANDS DIED
HAZARDS A SEICHE CAUSED FLOODING IN THE SOUTHERN BASIN OF THE DEAD SEA. FAULTING OCCURRED NORTH OF THE DEAD SEA (120 km IN LENGTH). A TSUNAMI WAS RECORDED ALONG THE EGYPTIAN & SYRIAN COAST
SOURCE 1,5,6,12,13,22,30,31,38
COMMENT (38) INCORRECTLY GIVES THE EPICENTRE AS SYRIA

116.
DATE AD 747/748
FAULT DEAD SEA
FELT IN SYRIA, ISRAEL, JORDAN, EGYPT
DETAILS DAMAGE IN JERUSALEM, JERICHO, NABLUS & TIBERIAS. AFFECTED DAMASCUS (MODERATE), ALEPPO AND ANTIOCH
SOURCE 2,8,14,19,24,31
COMMENT SAME AS 115?

117.
DATE AD 749
FELT IN SYRIA
DETAILS AFFECTED DAMASCUS
SOURCE 1,2,8
COMMENT SAME AS 118?

118.
DATE AD 749 Jan 25
EPICENT. NEAR HATRA (AL-HADR), IRAQ
FELT IN IRAQ
DETAILS AFFECTED JAZIRAH. DAMAGE TO TOWNS NORTH EAST OF THARTHAR
HAZARDS 7km FAULT NEAR HATRA
SOURCE 5

119.
DATE AD 756 Mar 8
FELT IN ISRAEL, SYRIA
DETAILS JERUSALEM DAMAGED. INTENSITY IN ISRAEL =6-7
SOURCE 6,9,30

120.
DATE AD 765 May 3
FAULT DEAD SEA
MAG. ML 6.2
FELT IN ISRAEL, SYRIA
DETAILS PARTIAL DAMAGE IN JERUSALEM. FELT IN NORTH SYRIA
SOURCE 6,12
COMMENT (19) IS LESS SPECIFIC CONCERNING THE DATE AND CITES AD 758-775. A SEPERATE DAMAGE REPORT BY (6) CITES SEVERE EARTHQUAKE DAMAGE IN THE TEMPLE AREA OF JERUSALEM BETWEEN AD 750-780

121.
DATE AD 775
FELT IN ISRAEL, SYRIA
DETAILS NO DETAILS AVAILABLE CONCERNING THIS EVENT
SOURCE 19
COMMENT CONFUSED REPORTS

122.
DATE AD 775
FAULT NORTH LEVANT
MAG. 6.3
FELT IN SYRIA
DETAILS AFFECTED ANTIOCH
SOURCE 12,19
COMMENT SAME AS 121?

123.
DATE AD 796 Apr
EPICENT. OFF ALEXANDRIA, EGYPT
INTENS. 10-11
MAG. ML 7.2
FELT IN EGYPT
DETAILS INTENSITY AT ALEXEXANDRIA =8. THE SPIRE OF THE PHAROS LIGHTHOUSE (CONSTRUCTED IN BC 270) TOPPLED. FELT AT DIFFERENT LOCALITIES ACROSS EGYPT. (21) CITES THE EPICENTRAL INTENSITY AS 6 & THE MAGNITUDE AS 5.2
SOURCE 1,12,20,21

124.
DATE AD 808
FELT IN ISRAEL
DETAILS CHURCH DAMAGED IN JERUSALEM. INTENSITY IN ISRAEL =6-7
SOURCE 6,9,30

125.
DATE AD 811
FELT IN ISRAEL, LEBANON
HAZARDS TSUNAMI ON THE COASTS OF ISRAEL & LEBANON
SOURCE 22,30

126.

DATE	AD 827
FELT IN	YEMEN A.R, YEMEN P.D.R
DETAILS	AFFECTED SAN'A. AT ADEN THE INTENSITY =8. FELT THROUGHOUT YEMEN DOWN TO ADEN
SOURCE	1,4,20

127.

DATE	AD 834
FELT IN	IRAQ
SOURCE	1

128.

DATE	AD 835
FAULT	NORTH LEVANT
MAG.	6.1
FELT IN	SYRIA
DETAILS	INTENSITY AT ANTIOCH =8-9
SOURCE	1,8,12,24

129.

DATE	AD 839
EPICENT.	IRAN
FELT IN	IRAN, SYRIA
DETAILS	INTENSITY AT AHVAZ =10. FELT AT JEBBE
SOURCE	1,2

130.

DATE	AD 845
MAG.	6.5?
FELT IN	SYRIA, IRAQ
DETAILS	INTENSITY AT DAMASCUS & AT ANTIOCH =9. FELT AT MOSUL. 50,000 DEAD
SOURCE	1,2
COMMENT	ACCORDING TO (12) A LARGE EVENT OCCURRED ON THE NORTH LEVANT FAULT IN AD 844

131.

DATE	AD 847, possibly Nov 24
FAULT	possibly BEKA'A, LEBANON
MAG.	ML 6.2
FELT IN	LEBANON, SYRIA, LIBYA, ALGERIA, TUNISIA, IRAN, IRAQ, JORDAN
DETAILS	DESTRUCTION IN LEBANON. AFFECTED DAMASCUS (INTENSITY =8) & HOMS. 20,000 DEAD AT ANTIOCH & 50,000 AT MOSUL. (2) GIVES GEZIR (IRAN) AS EPICENTRE. DAMAGE EXTENDED TO DARAYYA, EL-MAZAR, BEIT-LIQYA AND EL SOUTH
SOURCE	1,2,5,8,12,24
COMMENT	POSSIBLY MORE THAN 1 EVENT. THE FACT THAT TUNISIA & ALGERIA WERE AFFECTED WOULD SEEM TO SUGGEST A LARGE MEDITERRANEAN EVENT

132.

DATE	AD 849
MAG.	5.3
FELT IN	IRAQ
DETAILS	FELT IN BAGHDAD
SOURCE	5,16,18

133.

DATE	AD 854
FELT IN	ISRAEL
DETAILS	INTENSITY AT TIBERIAS =10-11
HAZARDS	GROUND FAILURE AT TIBERIAS
SOURCE	1,6

134.

DATE	AD 856 Dec 3-30
EPICENT.	GREECE, CORINTH
MAG.	7.9 (16)
FELT IN	SYRIA, EGYPT, TUNISIA, ISRAEL, YEMEN A.R. POSSIBLY ALSO IRAN & IRAQ
DETAILS	45,000 DEAD (SOME CITE THIS NUMBER DEAD IN TUNIS ALONE). STONES FELL ON EGYPT. INTENSITY IN ISRAEL =6-7. BADLY AFFECTED CORINTH & PATRAS. SOME SUGGEST 2 EVENTS: 1 IN TUNIS AND 1 IN GREECE (cont.)

HAZARDS	LARGE LANDSLIDES & BLOCK MOVEMENTS IN YEMEN A.R.
SOURCE	2,8,20,24,31,38
COMMENT	SOME CONFUSION EXISTS BETWEEN REPORTS CONCERNING THIS EVENT AND 135

135.

DATE	AD 856 Dec 22
EPICENT.	NEAR QOM, IRAN (36.09^{O}N 54.22^{O}E)
MAG.	ML 7.9
FELT IN	IRAN, IRAQ, SYRIA, ISRAEL, TURKEY. POSSIBLY ARABIA & YEMEN A.R. ALSO
DETAILS	EXTREME EVENT KILLING 200,000. AFFECTED QUMIS DAMGHAN (INTENSITY =10-11), KHURASAN (INTENSITY =10-11), ALAMANA & HAMADAN. 45,000 KILLED AT KHURASAN. INTENSITY AT BAGHDAD =8. THE EARTHQUAKE WAS FELT ACROSS THE EUPHRATES
SOURCE	1,5,6,12,13,16,19,27,31

136.

DATE	AD 857
FELT IN	EGYPT
DETAILS	INTENSITY AT CAIRO =7
SOURCE	1

137.

DATE	AD 859 Apr 8 or Dec
EPICENT.	SYRIA
FAULT	NORTH LEVANT
MAG.	ML 8.0
FELT IN	SYRIA, TURKEY, EGYPT, ARABIA, IRAQ, ISRAEL
DETAILS	INTENSITY AT ANTIOCH =10-11 (LIQUEFACTION), TINIS =9, BAGHDAD =8, BELBEIS =6. URFA, ADANA, TARSUS, MISIS, HOMS & DAMASCUS WERE DESTROYED. THE EARTHQUAKE ALSO AFFECTED RAQQA, HARRAN & RAS-EL-AIN. SPRINGS SANK AT MECCA. ALEXANDRIA & THE NILE DELTA WERE AFFECTED AS WAS THE TEMPLE AREA OF JERUSALEM
HAZARDS	COASTAL LANDSLIDES & TSUNAMI AT SAMANDAG & LATAKIA. GROUND FAILURE/LIQUEFACTION AT ANTIOCH
SOURCE	1,2,3,5,6,8,12,15,20,21,22,38
COMMENT	(22) CITES THE DATE AS Nov 24

138.
DATE AD 871 Nov - 872 Nov (possibly AD 872 Jun 22)
EPICENT. IRAN
FELT IN IRAN, IRAQ
DETAILS INTENSITY AT WASIT =8-9. AFFECTED BADRAH (NORTH EAST OF AL-KUT). ALSO SAMARRA VALLEY, SIRWAN & TANG-I-SIKA IN RUDBAR VALLEY. 20,000 DEAD
SOURCE 1,2,5,8,27
COMMENT (5) SUGGESTS 3 EVENTS

139.
DATE AD 873 Jun 20
FELT IN IRAQ
DETAILS INTENSITY AT BASRA =9
SOURCE 1
COMMENT SAME AS 138?

140.
DATE AD 874
FELT IN ARABIA
DETAILS INTENSITY =8
SOURCE 1

141.
DATE AD 880
FELT IN SYRIA
SOURCE 19
COMMENT SAME AS 142?

142.
DATE AD 880 Nov 22
FELT IN IRAQ
DETAILS INTENSITY AT BAGHDAD =7
SOURCE 1

143.
DATE 881 Apr 8
EPICENT. OFF COAST ACRE, ISRAEL
MAG. ML 6.5
FELT IN ISRAEL
DETAILS NO DAMAGE REPORTED
HAZARDS TSUNAMI AT ACRE, ISRAEL. (23) REPORTS A TSUNAMI ST. CORDOVA, (SPAIN) ON THIS DAY
SOURCE 6,12,30

144.
DATE AD 881 Oct
EPICENT. IRAN
FELT IN IRAQ
DETAILS AFFECTED BAGHDAD
SOURCE 2,5,16

145.
DATE AD 885 Nov
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =9-10
SOURCE 1

146.
DATE AD 893
FELT IN ARABIA
DETAILS AFFECTED YAMAN
SOURCE 13
COMMENT DOUBTFUL EVENT

147.
DATE 893 Feb
FELT IN IRAN
DETAILS INTENSITY AT ARDABIL =9. 150,000 DEAD. 6
EARTHQUAKES AT ARDABIL DURING THIS PERIOD
SOURCE 1,2
COMMENT ANOTHER EARTHQUAKE POSSIBLY OCCURRED ON Dec 24

148.
DATE AD 894 Mar 12
EPICENT. IRAN
MAG. ML 7.6
FELT IN ISRAEL, SYRIA
DETAILS THE EPICENTRAL REGION WAS POSSIBLY IN ARMENIA.
(38) CITES AN EVENT IN YEREVAN, ARMENIA IN THIS
YEAR
SOURCE 6,12,19
COMMENT SAME AS 147?

149.
DATE AD 902 Jun
EPICENT. IRAN
FELT IN IRAQ
DETAILS INTENSITY AT BAGHDAD =9. GREAT DAMAGE WAS CAUSED IN JIBAL & IN THE KURDISTAN REGION. THE AREA BETWEEN QASR-SHIRIN & KIRIND WAS DEVASTATED. HULWAN TOTALLY DESTROYED. ALSO AFFECTED KHANAQIN & JALULA
HAZARDS SUBSIDENCE AT BASRA & BA'QUBAH, IRAQ
SOURCE 1,2,5,16

150.
DATE AD 933/934
FELT IN EGYPT
DETAILS (20) STATES THAT AN EARTHQUAKE IN AD 934 LAID MANY HOUSES & VILLAGES LOW
SOURCE 1,20

151.
DATE AD 935 Oct 5
FELT IN EGYPT
DETAILS INTENSITY =8
SOURCE 1

152.
DATE AD 950 Jul 26
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =8-9
SOURCE 1

153.
DATE AD 951 Sep
FELT IN SYRIA, TURKEY
DETAILS INTENSITY AT ALEPPO =8-9. AFFECTED THE BORDER ZONE
SOURCE 1,3

154.
DATE AD 951 Sep 15
FELT IN EGYPT
DETAILS INTENSITY AT ALEXANDRIA =8-9
SOURCE 1

155.
DATE AD 956 Jan 1
FELT IN EGYPT
DETAILS INTENSITY AT ALEXANDRIA =8 & AT FOSTAT (CAIRO) =6. A LARGE EVENT. (20) MENTIONS A SERIES OF EARTHQUAKE SHOCKS IN EGYPT FOR 954
SOURCE 1,2
COMMENT POSSIBLY AN OFF-SHORE EPICENTRE?

156.
DATE AD 958 Mar 24 or Feb 23
EPICENT. IRAN
MAG. ML 8.0
FELT IN ISRAEL, SYRIA, TURKEY, IRAQ, EGYPT?
DETAILS AFFECTED QOM & HALVAN IN IRAN & KAMAN IN TURKEY. ALSO AFFECTED BAGHDAD & JEBLE. SOME DEAD IN IRAN AT RAYY & TALIGAN
SOURCE 2,5,12,16,31
COMMENT EGYPT WAS REPEATEDLY SHAKEN BY EARTHQUAKES AT THIS TIME, BUT IT SEEMS UNLIKELY THAT THE EVENT IN IRAN WOULD AFFECT EGYPT

157.
DATE 958 Apr
EPICENT. IRAN
MAG. ML 6.4 (16)
FELT IN IRAQ
DETAILS INTENSITY AT BAGHDAD =8
SOURCE 1,16

158.
DATE AD 963 May 12
FELT IN EGYPT
SOURCE 1

159.
DATE AD 963 Jul 22
FAULT NORTH LEVANT
MAG. 6.3
DETAILS NO DETAILS CONCERNING THIS EVENT
SOURCE 12

160.
DATE AD 969 Jul 1
FELT IN EGYPT
SOURCE 1

161.
DATE AD 972 Oct - 973 Oct
FAULT NORTH LEVANT
MAG. 6.1
FELT IN SYRIA
DETAILS INTENSITY AT ANTIOCH =9. CASTLES RUINED IN SYRIA
SOURCE 1,2,3,8,12
COMMENT UNCERTAINTY ABOUT YEAR

162.
DATE AD 973 Nov
FELT IN IRAQ
DETAILS AFFECTED WASIT. (5) REFERS TO 2 EVENTS: THIS ONE AND ANOTHER EVENT BETWEEN Oct 973 - Oct 974
SOURCE 2,5

163.
DATE AD 974
FELT IN SYRIA
DETAILS INTENSITY AT DAMASCUS =8-9
SOURCE 1
COMMENT PART OF 162?

164.
DATE AD 975
FELT IN IRAQ
SOURCE 1

165.
DATE AD 977 Nov
EPICENT. IRAN
FELT IN IRAQ
DETAILS BAGHDAD SHAKEN SEVERAL TIMES
SOURCE 1,2,5

166.

DATE	AD 978 Jun 17
EPICENT.	IRAN
FELT IN	IRAN, IRAQ
DETAILS	AFFECTED SIRAF IN IRAN. (16) SUGGESTS SEVERAL EARTHQUAKES
SOURCE	1,16

167.

DATE	AD 986
FELT IN	IRAQ
DETAILS	INTENSITY AT MOSUL =8-9. MANY DEAD
SOURCE	1,2,5

168.

DATE	AD 991 Apr 5
FAULT	BEKA'A
MAG.	ML 6.5
FELT IN	LEBANON, SYRIA, EGYPT
DETAILS	AFFECTED BA'ALBEK. AT DAMASCUS THE INTENSITY =9
SOURCE	1,12,13,19,22,38

169.

DATE	AD 992
FELT IN	SYRIA
SOURCE	19
COMMENT	SAME AS ABOVE?

170.

DATE	AD 995
FELT IN	SYRIA
SOURCE	1

171.

DATE	AD 996 - 1020
FELT IN	EGYPT
DETAILS	EGYPT AFFECTED BY MANY EARTHQUAKES AT THIS TIME
SOURCE	2
COMMENT	ACCORDING TO (38) THERE WAS AN EARTHQUAKE IN THE AEGEAN SEA ON Mar 29, 1000 AD, THAT WAS FELT THROUGHOUT THE EASTERN MEDITERRANEAN

172.
DATE AD 1002
FELT IN SYRIA
DETAILS FELT IN SYRIA & THE BORDER ZONE. INTENSITY =8-9
SOURCE 1,2,3,8,24

173.
DATE AD 1002+
FELT IN ISRAEL, JORDAN
DETAILS AFFECTED THE JORDAN VALLEY CAUSING LOSS OF LIFE
SOURCE 6,7

174.
DATE AD 1007
FELT IN IRAQ
DETAILS AFFECTED TIGRIS-TESIPHON AND BAGHDAD KILLING 10,000
SOURCE 5,8,13
COMMENT SAME AS 175?

175.
DATE AD 1008 Apr 27
FELT IN IRAN
DETAILS INTENSITY AT DAINAWAR =10-11 (THE GROUND CRACKED). 16,000 DEAD. ANOTHER EARTHQUAKE OCCURRED IN May WITH INTENSITY AT SIRAF =9
HAZARDS A TSUNAMI OCCURRED AT SHIRAZ IN ASSOCIATION WITH THE FIRST EVENT. THIS WRECKED MANY SHIPS AT SEA
SOURCE 1,2

176.
DATE AD 1016
FELT IN ISRAEL
DETAILS STRONG IN JERUSALEM. INTENSITY IN ISRAEL =6-7
SOURCE 6,7,9,30

177.

DATE	AD 1029 Jan 20
FAULT	NORTH LEVANT
MAG.	6.3
FELT IN	SYRIA
DETAILS	AFFECTED DAMASCUS
SOURCE	12,13
COMMENT	AN EARTHQUAKE OCCURRED IN SYRIA IN AD 1030 ACCORDING TO (19)

178.

DATE	AD 1031
FELT IN	IRAQ, IRAN
DETAILS	MOSUL SHAKEN 3 TIMES. 50 HOUSES DESTROYED & 4 PEOPLE KILLED
SOURCE	5,8

179.

DATE	AD 1032 Mar 6
EPICENT.	OFF GAZA, ISRAEL
MAG.	ML 6.9
FELT IN	ISRAEL
DETAILS	STRONG EARTHQUAKE AFFECTING JERUSALEM, ASCALON, GAZA & NEGEV. HEAVY DAMAGE CAUSED. INTENSITY IN ISRAEL =6-7
HAZARDS	TSUNAMI AT GAZA & ASCALON, ISRAEL
SOURCE	6,9,12,30

180.

DATE	AD 1034 Jan 4 (or 1033 Dec 5)
EPICENT.	OFF COAST ACRE, ISRAEL
MAG.	ML=6.2?
FELT IN	ISRAEL, LEBANON, SYRIA, EGYPT
DETAILS	INTENSITY AT TIBERIAS =10-11. RAMLE WAS 1/3 TO 1/2 DESTROYED. GAZA, ACRE, JERUSALEM, NABLUS, HEBRON & ASCALON SUFFERED HEAVY DAMAGE. FELT IN THE CITIES OF NEGEV AND GALILEE. 70,000 DEAD. SHOCKS FELT IN EGYPT. INTENSITY IN ISRAEL =8 OR ABOVE
HAZARDS	TSUNAMI AT ACRE & ALONG THE COAST OF ISRAEL & LEBANON. GROUND FAILURE AT TIBERIAS
SOURCE	1,2,6,9,12,19,20,22,30
COMMENT	CITED AS 2 EVENTS IN SOME CATALOGUES

181.
DATE AD 1035
FELT IN ISRAEL
DETAILS AFFECTED JERUSALEM (MODERATE) FOR 40 DAYS
SOURCE 6,19

182.
DATE AD 1042 Aug 21 - 1043 Aug 9
EPICENT. NEAR PALMYRA, SYRIA
FAULT LEVANT SECONDARY (12)
MAG. ML 7.2
FELT IN SYRIA, LEBANON, EGYPT & POSSIBLY IRAN
DETAILS PALMYRA DESTROYED. STRONG IN BA'ALBEK. 50,000 DEAD. (8) & (24) COMBINE THIS EVENT WITH THE ONE LISTED BELOW FOR IRAN
SOURCE 1,2,12,31
COMMENT CONFUSED WITH 163

183.
DATE AD 1042 Nov 24
EPICENT. TABRIZ, IRAN
MAG. 7.6
FELT IN IRAN
DETAILS INTENSITY =8-9 IN TABRIZ WHERE THE CASTLE AND WALLS OF THE CITY WERE DESTROYED. 40,000 DEAD
SOURCE 1,2,16,31
COMMENT CONFUSED WITH 182

184.
DATE AD 1047
FELT IN ISRAEL
DETAILS INTENSITY AT RAMLE =9
SOURCE 1

185.
DATE AD 1053 Sep/Oct
FELT IN IRAQ, IRAN
DETAILS BAGHDAD SHAKEN BY AN EARTHQUAKE WHICH EXTENDED TO HAMADAN (IRAN). ALSO AFFECTED WASIT, ANAH & TIKRIT
SOURCE 2,5

186.

DATE	AD 1058 Oct
FELT IN	IRAQ
DETAILS	MANY DIED IN MOSUL. ANOTHER EARTHQUAKE A FEW MONTHS LATER (POSSIBLY Dec 2) AFFECTED THE AREA BETWEEN KIRKUK & MOSUL WITH INTENSITY =9 AT MOSUL. THIS DESTROYED TOWNS IN JAZIRAH & CAUSED HEAVY DAMAGE IN TIKRIT, WASIT & ANAH. IT WAS ALSO STRONG IN BAGHDAD & HAMADAN. ACCORDING TO (16) A SEVERE EARTHQUAKE OCCURRED IN IRAN ON Dec 8, 1058
SOURCE	1,5,13,18
COMMENT	CONFUSED REPORTS - SAME AS 185?

187.

DATE	AD 1060
FAULT	DEAD SEA
MAG.	ML 6.1
FELT IN	ISRAEL
DETAILS	JERUSALEM SHAKEN, STRONG IN JUDAEA
SOURCE	6,7,12

188.

DATE	AD 1063 Jul/Aug
EPICENT.	POSSIBLY ANATOLIA, TURKEY
FAULT	NORTH LEVANT
MAG.	ML 7.1
FELT IN	SYRIA, ISRAEL, LEBANON, IRAQ, JORDAN, TURKEY
DETAILS	INTENSITY AT ANTIOCH =8. DAMAGE IN TRIPOLI, ACRE (INTENSITY =8), TYRE & WASIT. ALSO AFFECTED SUL (JORDAN) & LAODICEA (TURKEY)
SOURCE	1,2,3,6,8,12,13,14,24
COMMENT	(38) CITES AN EVENT ON Sep 23 OF THIS YEAR THAT AFFECTED IZNIK & ISTANBUL

189.

DATE	AD 1067 Apr 20
FAULT	ARAVA
MAG.	ML 6.5
FELT IN	ISRAEL
DETAILS	DESTRUCTION OF EILAT
SOURCE	12,24

190.
DATE AD 1068 Mar 18
EPICENT. OFF THE COAST OF YAVNE, ISRAEL
MAG. ML 7.0
FELT IN ISRAEL, IRAQ, SYRIA, ARABIA, EGYPT
DETAILS INTENSITY AT JERUSALEM, RAMLE & EILAT =9. IN RAMLE ONLY 2 HOUSES REMAINED STANDING & 25,000 PEOPLE WERE KILLED. HAIFA WAS DESTROYED & ALL ITS INHABITANTS KILLED. THE EARTHQUAKE ALSO AFFECTED HIJAZ, WADI-EL-SZAFRH (INT. =6), KHAYBAR (INT. =9), BEDR, YANBAN, WADI QORHA, TAYMA (INT. =9), TABUK, SHARM YANBU (INT. =6), KUFA (INT. =8), BANIYAS (INT. =9) & TINIS (NEAR DUMYAT)
HAZARDS TSUNAMI IN ISRAEL AT ASHDOD, YAVNE & HOLOTS
SOURCE 1,2,5,6,8,9,12,20,22,30
COMMENT (19) & (24) CITE THE DATE AS AD 1069

191.
DATE AD 1070 Feb 25
FAULT ARAVA
MAG. 6.5
FELT IN ISRAEL, EGYPT
DETAILS STRONG IN RAMLE. AFFECTED CAIRO. INTENSITY IN ISRAEL =6-7
SOURCE 2,6,8,9,12,30

192.
DATE AD 1072
FELT IN YEMEN A.R.
DETAILS AFFECTED SAN'A, ZABID & MUKHA
SOURCE 4

193.
DATE AD 1072 Feb 26
FELT IN IRAQ, IRAN
DETAILS INTENSITY AT BAGHDAD =6-8 & AT FARS (IRAN) =8
SOURCE 1,5

194.
DATE AD 1085
FELT IN IRAN
DETAILS INTENSITY AT ARRADJAN (ZAGROS REGION) =8
SOURCE 1

195.

DATE	AD 1086
FELT IN	IRAQ, SYRIA
DETAILS	AFFECTED JAZIRAH & BADHARAYA
SOURCE	1,2,5,8,24
COMMENT	(19) CITES A SYRIAN EARTHQUAKE IN AD 1087. SIMILARLY, (12) CITES A MAGNITUDE 6.1 EVENT ON THE NORTH LEVANT FAULT IN 1087

196.

DATE	AD 1091 Sep 17 or AD 1092
FAULT	NORTH LEVANT
MAG.	6.2?
FELT IN	SYRIA, ASIA MINOR
DETAILS	INTENSITY AT ANTIOCH =9. 90 VILLAGES WERE DESTROYED. THE EARTHQUAKE WAS FELT AT HOMS, HAMA, ALEPPO, ANTIOCH & DAMASCUS
SOURCE	1,8,12,13,14,19,24,38

197.

DATE	AD 1094 Feb
EPICENT.	IRAQ
FELT IN	IRAN, IRAQ
DETAILS	AFFECTED BAGHDAD
SOURCE	1,16

198.

DATE	AD 1094 Jun
FELT IN	SYRIA
DETAILS	INTENSITY AT DAMASCUS =6
SOURCE	1
COMMENT	(19) CITES AD 1095 AS THE YEAR OF A SYRIAN EARTHQUAKE

199.

DATE	AD 1098
FELT IN	SYRIA
DETAILS	AFFECTED CENTRAL SYRIA, ALEPPO & ANTIOCH
SOURCE	19

200.

DATE	AD 1105 Dec 24
FAULT	LEVANT SECONDARY
INTENS.	8
MAG.	ML 6.1
FELT IN	ISRAEL
DETAILS	STRONG IN JERUSALEM. INTENSITY IN ISRAEL =6-7
SOURCE	6,7,9,12,30

201.

DATE	AD 1109
FAULT	NORTH LEVANT
MAG.	6.1
DETAILS	NO ACTUAL DAMAGE REPORTS
SOURCE	12

202.

DATE	AD 1111 May 26
INTENS.	6-7
MAG.	5.8
FELT IN	EGYPT
DETAILS	AFFECTED EAST CAIRO. DESTRUCTION OF RE-HACHOPE TEMPLE. FELT OVER AN AREA OF 25,000 sq km. (20) CITES March OF THIS YEAR AS A TIME OF MANY EARTHQUAKE SHOCKS IN EGYPT
SOURCE	22,28

203.

DATE	AD 1113 Jul 18 and Aug 9
FAULT	NORTH LEVANT
MAG.	6.3
FELT IN	SYRIA, ISRAEL, EGYPT
DETAILS	2 SHOCKS AFFECTING ALEPPO, HOMS & JERUSALEM
SOURCE	6,12,19

204.

DATE	AD 1114 Mar 12
INTENS.	9
FELT IN	TURKEY
DETAILS	AFFECTED SAMSAT, KOZAN, MARAS, KEYSUN. MODERATE DAMAGE IN TURKEY
SOURCE	13,31,38

205.
DATE AD 1114 Jun 7 - 1115 May 26
EPICENT. TURKEY
FELT IN TURKEY
DETAILS 40,000 DEAD. 13 SETTLEMENTS AROUND URFA WERE DESTROYED & THE WALLS OF HARRAN COLLAPSED. SAMSAT WAS DESTROYED. IN EL-SUN 100 HOUSES & HALF OF THE FORTRESS WERE DESTROYED
SOURCE 2,27,31

206.
DATE AD 1115 Dec 25
EPICENT. TAURUS MOUNTAINS
MAG. ML 7.5
FELT IN SYRIA, ISRAEL
DETAILS DISASTEROUS IN ALEPPO & ANTIOCH. INTENSITY IN JERUSALEM =5. OTHER CITIES WERE BADLY DAMAGED
SOURCE 2,6,12

207.
DATE AD 1117 Jun 26
FELT IN ISRAEL
DETAILS MANY DAMAGED BUILDINGS IN JERUSALEM. A STRONG EARTHQUAKE EVENT WITH INTENSITY IN ISRAEL =6-7
SOURCE 6,7,9,30

208.
DATE AD 1118 Mar
FELT IN IRAQ
DETAILS INTENSITY AT BAGHDAD =5-6. ACCORDING TO (16) AN EARTHQUAKE OCCURRED IN IRAN ON Apr 3 OF THIS YEAR WITH MAGNITUDE =5.9
SOURCE 1,2

209.
DATE AD 1119 Dec 10
EPICENT. IRAN
FELT IN ISRAEL
SOURCE 2,12
COMMENT ACCORDING TO (1), AN EARTHQUAKE OCCURRED IN IRAN ON Dec 11. THIS AFFECTED QAZVIN (INT. =8-9)

210.
DATE AD 1122
FELT IN ARABIA
DETAILS HIJAZ SHAKEN. INTENSITY AT MEDINA =8
SOURCE 1,13

211.
DATE AD 1127
FELT IN SYRIA, LEBANON
SOURCE 13

212.
DATE AD 1129
FELT IN IRAQ
DETAILS STRONG EARTHQUAKE IN BAGHDAD
SOURCE 5,18

213.
DATE AD 1135 Mar
EPICENT. IRAN
FELT IN IRAQ
DETAILS INTENSITY AT BAGHDAD =7
SOURCE 1,16

214.
DATE AD 1135 Jul 25
EPICENT. IRAN
MAG. M 6.1
FELT IN IRAQ
DETAILS BY Jul 31, 9 SHOCKS HAD SHAKEN BAGHDAD
SOURCE 1,2,5,16

215.
DATE AD 1137
FELT IN IRAQ, SYRIA
DETAILS STRONG EARTHQUAKES IN SYRIA AND IRAQ. MANY DEAD.
AFFECTED MESOPOTAMIA
SOURCE 1,5

216.

DATE AD 1137 Sep 19 - 1138 Sep 7

FELT IN IRAQ, SYRIA

DETAILS INTENSITY AT MOSUL =8-9. SERIOUS DAMAGE IN JAZIRAH & MANY PEOPLE WERE KILLED IN THE MOSUL/AS-SINN REGION. (1) & (24) CITE THE YEAR OF THIS EARTHQUAKE 1137 (Oct)

SOURCE 1,2,5,24

COMMENT POSSIBLY 2 EVENTS

217.

DATE AD 1138 Oct

EPICENT. NORTH EAST of ALEPPO? SYRIA (12)

FAULT NORTH LEVANT? (12)

MAG. ML 7.2

FELT IN SYRIA, IRAQ, EGYPT, IRAN

DETAILS INTENSITY AT DAMASCUS =7-8. ESPECIALLY BAD AT ALEPPO WHERE THE INTENSITY =10-11. ALEPPO WAS SHAKEN 80 TIMES IN ONE NIGTHT AND TOTALLY DESTROYED. 100,000-250,000 DEAD AT AL-HERA (NEAR KUFA) IN MESOPOTAMIA. INTENSITY AT GANZAH IN ARMENIA =12 & AT HULWAN =10-11. 230,000? DIED IN THE REGION OF GANZAH. EGYPT & SYRIA WERE SHAKEN FOR MANY DAYS

HAZARDS LIQUEFACTION AT GANZAH

SOURCE 1,2,3,5,8,12,13,19

COMMENT ACCORDING TO (3) THE EARTHQUAKE WAS IN Nov 1139. (13) ALSO GIVES THE YEAR AS 1139, WHEREAS (12) CITES THE DATE AS 13/9/1137. COULD THIS EARTHQUAKE REPORT BE A COMBINATION OF 2 LARGE EARTHQUAKE EVENTS?

218.

DATE AD 1149

FELT IN IRAQ

DETAILS BAGHDAD SHAKEN 10 TIMES. AT HULWAN (MESOPOTAMIA) A MOUNTAIN WAS SHATTERED. MANY DEAD

HAZARDS LANDSLIDE OR FAULTING AT HULWAN. LANDSLIDE AT ARASH (CAUCASUS)

SOURCE 2,5

COMMENT (5) CITES 2 SEPERATE EVENTS WITH 2 SEPERATE LANDSLIDES. SEE 219 ALSO

219.
DATE AD 1150 Apr 1
EPICENT. IRAN
MAG. M 5.9
FELT IN IRAQ, IRAN
DETAILS INTENSITY AT BAGHDAD =7-8. AT HULWAN INTENSITY =10
HAZARDS LANDSLIDE AT ARASH, CAUCASUS KILLED MANY
SOURCE 1,2,5,16
COMMENT SAME AS 218?

220.
DATE AD 1151 Sep 28
EPICENT. GEBEL ED-DRUZ, SYRIA
FAULT LEVANT SECONDARY
INTENS. 9
MAG. ML 6.2
FELT IN SYRIA, ISRAEL, JORDAN
DETAILS INTENSITY AT BUSRA =8. DESTRUCTIVE AT LEJA. AFFECTED HAURAN. STRONG IN JORDAN ESPECIALLY AT TRACHONITE (TRACHONITIS=ANCIENT DISTRICT OF NORTH PALESTINE). INTENSITY IN ISRAEL =6-7
SOURCE 1,6,9,12,19,30

221.
DATE AD 1152 Feb 2
FELT IN SYRIA
DETAILS INTENSITY AT DAMASCUS =6
SOURCE 1,19

222.
DATE AD 1154
FELT IN YEMEN A.R., YEMEN P.D.R.
DETAILS INTENSITY AT SAN'A =8
SOURCE 1,4

223.
DATE AD 1154 or 1155
FELT IN IRAQ
DETAILS RIVER TIGRIS AFFECTED ESPECIALLY AT WASIT - THE WATER DISAPPEARED & AT WASIT TURNED RED
SOURCE 2,5

224.

DATE	AD 1155
FAULT	NORTH LEVANT
MAG.	6.6
FELT IN	SYRIA, LEBANON, TURKEY
DETAILS	AFFECTED SOUTHERN TURKEY ESPECIALLY LATAKIA. ALSO AFFECTED ANTIOCH, DAMASCUS & TRIPOLI. 2,000 TO 3,000 DEAD
SOURCE	12,13,19,31,38

225.

DATE	AD 1156
FELT IN	ISRAEL
DETAILS	STRONG EARTHQUAKE - CONTINUING FOR 1 MONTH. (38) GIVES INTENSITY IN ISRAEL AS 6-7
SOURCE	6,9,38
COMMENT	PART OF SYRIAN EARTHQUAKE SERIES?

226.

DATE	AD 1156 Jan
FELT IN	IRAQ
DETAILS	FELT IN BAGHDAD
SOURCE	1,5
COMMENT	AN EARTHQUAKE OCCURRED IN IRAN DURING Feb 1156 (16)

227.

DATE	AD 1156 May 16 - Dec 8
FELT IN	SYRIA
DETAILS	MANY SHOCKS IN SYRIA
SOURCE	2

228.

DATE	AD 1156 May 19
EPICENT.	TURKEY
MAG.	ML 7.6
FELT IN	ISRAEL, SYRIA, IRAQ
DETAILS	ALEPPO, HAMAT & HOMS BADLY SHAKEN MANY TIMES. ALEPPO WAS SHAKEN AGAIN ON May 23. OTHER SHOCKS OCCURRED ON Oct 18 & Oct 20-30 OF THIS YEAR. THEY CONTINUED UNTIL Dec 8
SOURCE	2,12

229.
DATE AD 1156 Oct 5
FELT IN SYRIA
DETAILS INTENSITY AT DAMASCUS =9-10. AFFECTED HAMAT
SOURCE 1

230.
DATE AD 1156 Oct 26
FELT IN SYRIA
DETAILS FELT BETWEEN ALEPPO & MALATYA FOR 14 MONTHS
SOURCE 13

231.
DATE AD 1156 Nov 18
FELT IN SYRIA
DETAILS ONE OF MANY EARTHQUAKE SHOCKS IN SYRIA AT THIS TIME
SOURCE 8
COMMENT AN EARTHQUAKE SWARM SEEMS TO HAVE OCURRED IN SYRIA DURING THE SECOND HALF OF THE 12th CENTURY

232.
DATE AD 1157 Feb 13-Dec 29
FELT IN SYRIA
DETAILS FELT REPEATEDLY IN SYRIA. SEE FOLLOWING RECORDS FOR DATES OF EARTHQUAKES AFFECTING ALEPPO, HAMAT (DEMOLISHED), SHEYZAR, HOMS, ANTIOCH & LATAKIA
SOURCE 2,8

233.
DATE AD 1157 Apr 2, Jul 5 & 14
FELT IN SYRIA
DETAILS Jul 5 - 4 SHOCKS OCCURRED. Jul 14 - SEVERAL SHOCKS. (12) CITES A MAJOR EVENT (ML 6.1) ON THE BEKA'A FAULT FOR Jul 15
SOURCE 8

234.

DATE	AD 1157 Aug 12
FAULT	NORTH LEVANT
INTENS.	10-11
MAG.	ML 7.3
FELT IN	SYRIA, ISRAEL
DETAILS	SEVERE IN SYRIA - DAMASCUS WAS DESTROYED. DESTRUCTION IN BA'ALBEK & IN APAMEA (DINAR), TURKEY. 15,000 DEAD?. SHIRAZ WAS DESTROYED. INTENSITY IN ISRAEL =6-7
SOURCE	6,8,12,30
COMMENT	(24) CITES 1 LARGE EVENT IN 1157. (27) SIMILARLY CITES ONE LARGE EVENT IN WHICH 40,000 DIED

235.

DATE	AD 1157 Aug 16-Dec 25
FELT IN	SYRIA
DETAILS	A SERIES OF MINOR SHOCKS: ON Aug 16 THREE SHOCKS OCCURRED. ON Sep 6 ONE SHOCK WAS FELT IN DAMASCUS. ON Oct 30 A SHOCK WAS FELT IN ALEPPO & HAMAT. ON Nov 15, Dec 14, Dec 23 and Dec 25 SHOCKS WERE FELT IN SYRIA
SOURCE	8
COMMENT	(13) CITES A MAJOR EVENT FOR 1158 IN SYRIA, LEBANON & TURKEY KILLING 20,000

236.

DATE	AD 1159 Jun 6
FELT IN	SYRIA, LEBANON
DETAILS	AFFECTED ORONTES VALLEY. INTENSITY AT ORONTES, ALEPPO, HAMAT, APAMEA (DINAR), SHAYZAR & HOMS =9-10. ALSO AFFECTED ANTIOCH & TRIPOLI. 20,000 DEAD
SOURCE	1,3,19
COMMENT	(3) CITES THE DATE AS BETWEEN 1156-1159

237.

DATE	AD 1160
FAULT	DEAD SEA
MAG.	ML 6.1
FELT IN	ISRAEL, JORDAN
DETAILS	SLIGHT IN JERUSALEM. ALSO AFFECTED BETHLEHEM. A MONASTRY WAS DESTROYED ON THE RIVER JORDAN
SOURCE	6,7,12,19

238.
DATE AD 1170 Jun 29 or 30
FAULT NORTH LEVANT
INTENS. 11-12
MAG. ML 7.9
FELT IN SYRIA, IRAQ, TURKEY, LEBANON, ISRAEL, EGYPT
DETAILS INTENSITY AT ALEPPO =9-10, ANTIOCH =9 & DAMASCUS =8. ALSO AFFECTED THE ORONTES VALLEY, BA'ALBEK, HOMS, FAHMYAH & APAMEA (DINAR) IN TURKEY, CAESAREA THROWN DOWN & INTENSITY AT JERUSALEM =5-6. TYRE, TRIPOLI & SIDON DAMAGED. FELT IN UPPER EGYPT & MESOPOTAMIA. 80,000 DEAD IN SYRIA
SOURCE 1,3,5,6,9,12,13,24,30,31
COMMENT (5) CITES THE DATE AS 1169-1170, (24) AS 1169 AND (31) AS 1171

239.
DATE AD 1172
FELT IN SYRIA, ASIA MINOR
SOURCE 19

240.
DATE AD 1177 May
EPICENT. IRAN
MAG. M 7.2
FELT IN IRAQ
DETAILS INTENSITY AT BAGHDAD =8
SOURCE 1,16

241.
DATE AD 1179 Sep
FAULT NORTH LEVANT
MAG. 6.7
FELT IN SYRIA, IRAQ, LEBANON
DETAILS INTENSITY AT ARBIL =10-11. ALSO AFFECTED ARMENIA, ANTIOCH & DAMASCUS. A GREAT EARTHQUAKE
HAZARDS LANDSLIDE AT ARBIL
SOURCE 1,2,5,8,12,19,24

242.
DATE AD 1182
EPICENT. GEBEL ED DRUZ, SYRIA
FAULT LEVANT SECONDARY
INTENS. 9-10
MAG. ML 6.7
FELT IN SYRIA, ISRAEL, JORDAN
DETAILS EARTHQUAKE AT GEBEL ED DRUZ. DESTRUCTIVE AT BUSRA & IN SOUTHERN SYRIA. MODERATE TO SEVERE IN JUDAEA & GALILEE. DESTRUCTIVE AT NABLUS. INTENSITY IN ISRAEL =6-7
SOURCE 6,9,12,13,24,30

243.
DATE AD 1183
FAULT NORTH LEVANT
MAG. ML 6.7
FELT IN SYRIA, LEBANON
DETAILS AFFECTED ANTIOCH & DAMASCUS. ALSO TRIPOLI. MORE THAN 20,000 DEAD
SOURCE 12,13,19,27,31,38

244.
DATE AD 1195-1196
FELT IN EGYPT, ARABIA
DETAILS MECCA SHAKEN. FELT ALL OVER EGYPT
SOURCE 2

245.
DATE AD 1201 Jun-Aug
EPICENT. NEAR BA'ALBEK, LEBANON ?
FAULT BEKA'A ?
INTENS. 11
MAG. ML 7.3
FELT IN LEBANON, SYRIA, IRAQ, EGYPT, GREECE, CYPRUS, IRAN, JORDAN, TURKEY
DETAILS INTENSITY AT BA'ALBEK =10-11. TRIPOLI DESTROYED AND MANY DEAD AT TYRE. THE INTENSITY AT DAMASCUS =9, MESOPOTAMIA =5-6, JERUSALEM =7-8, ACRE =8-9 & CAIRO =5-6. NABLUS DESTROYED WITH 30,000 DEAD. ALSO AFFECTED ANATOLIA &
(cont.)

ARMENIA. TOTAL DEAD = 1,100,000 (POSSIBLY ERRONEOUS - SEE COMMENT). INTENSITY IN ISRAEL =8

HAZARDS FAULTING AT BA'ALBEK

SOURCE 1,2,5,6,9,12,19,20,27,30

COMMENT (31) & (38) CITE A LARGE AEGEAN EARTHQUAKE IN THIS YEAR WHICH KILLED 100,000

246.

DATE AD 1202 May 20

EPICENT. NEAR BEYT SHEAN, ISRAEL

FAULT DEAD SEA

INTENS. 10-11

MAG. ML 6.8

FELT IN ISRAEL, JORDAN, EGYPT, CYPRUS, SYRIA, IRAQ

DETAILS AFFECTED THE ISRAELI COASTAL PLAIN & GALILEE. 30,000 WERE KILLED. INTENSITY AT JERUSALEM =5, SAFED =9, BEYT DAGAN =SM9, ACRE =8, NABLUS =SM7-8, BANIAS =9, TYRE =SM7 & HOMS =8. NABLUS WAS TOTALLY DESTROYED ACCORDING TO SOME REPORTS. ALSO AFFECTED UPPER EGYPT & HAURAN

HAZARDS A TSUNAMI AFFECTED SYRIA, EGYPT & CYPRUS ON May 22 (22)

SOURCE 1,2,5,6,7,9,12,20,30,31

COMMENT (6) CITES THE DATE AS Apr 20, AND (2) AS Apr-May

247.

DATE AD 1203 (1203-1204)

FELT IN EGYPT, SYRIA, CYPRUS, TURKEY, IRAQ, SICILY, MAGHREB, LEBANON, GREECE, ARABIA

DETAILS ALEPPO & TYRE BADLY DAMAGED. EFFECTS EXTENDED TO SABKA (SYRIA) & TO NORTH AFRICA. ALSO AFFECTED MESOPOTAMIA. (5) CITES 3 EVENTS DURING 1203-1204, BUT THERE WAS PROBABLY ONLY ONE

SOURCE 1,2,5,8,13,20

COMMENT EXACT YEAR UNCERTAIN

248.

DATE AD 1205 May

FELT IN YEMEN A.R.

SOURCE 1

249.
DATE AD 1208 Jan
FELT IN TURKEY, SYRIA
DETAILS INTENSITY AT DAMASCUS =6-7 & AT AHLAT (TURKEY) =9-10
SOURCE 1

250.
DATE AD 1212
FAULT NORTH LEVANT
MAG. 6.1
FELT IN SYRIA
DETAILS FELT AT ANTIOCH
SOURCE 12,19
COMMENT SAME AS 251?

251.
DATE AD 1212 May
FELT IN EGYPT, ISRAEL, JORDAN
DETAILS INTENSITY AT CAIRO =8. THE EVENT AFFECTED ALL EGYPT. IT ALSO AFFECTED EILAT (INT.=8-9) & KARAK (INT.=8)
SOURCE 1,2

252.
DATE AD 1225 Mar
FELT IN IRAQ
DETAILS INTENSITY AT MOSUL =7
SOURCE 1

253.
DATE AD 1226 May-Jun
FELT IN EGYPT
SOURCE 2

254.
DATE AD 1226 Nov 18
EPICENT. IRAN
MAG. M 6.5
FELT IN IRAQ, IRAN
DETAILS AFFECTED MOSUL
SOURCE 1,16

255.
DATE AD 1227
FELT IN IRAQ
DETAILS AFFECTED MOSUL, SULAYMANIYAH & TIKRIT
SOURCE 5
COMMENT SAME AS 254?

256.
DATE AD 1252
EPICENT. IRAN
FELT IN IRAQ
DETAILS INTENSITY AT BAGHDAD =5-6
SOURCE 1,16

257.
DATE AD 1256 Jun 28
FELT IN ARABIA
DETAILS INTENSITY AT MEDINA =4. AFFECTED HIJAZ. THIS EVENT WAS PROBABLY ASSOCIATED WITH A VOLCANIC ERUPTION SOUTH EAST OF MEDINA. ACCORDING TO (36) STRONG EARTHQUAKES COMMENCED 3 DAYS BEFORE THE ERUPTION. DURING THE ERUPTION LAVA FLOWED IN A NORTH & NORTH WEST DIRECTION TO THE FOOT OF DJEBEL WAIRA. THE LAVA FIELD IS 19 km LONG & 6 km WIDE
HAZARDS VOLCANIC ERUPTION, ARABIA
SOURCE 1,2,40
COMMENT (20) GIVES THE DATE AS Jul 1st, & (40) AS Jul 15 +/- 45 DAYS

258.
DATE AD 1258-1259
FELT IN EGYPT
SOURCE 2

259.
DATE AD 1259 Mar
FELT IN SYRIA
DETAILS INTENSITY IN DAMASCUS =6
SOURCE 1

260.
DATE AD 1259 Nov 22
FELT IN YEMEN A.R.
DETAILS SLIGHT SHOCK AT SAN'A
SOURCE 4

261.
DATE AD 1259 Dec 10
FELT IN YEMEN A.R.
DETAILS AFFECTED SAN'A. THERE WAS GREATER DAMAGE IN THE MOUNTAINS TO THE WEST OF THE TOWN
SOURCE 4

262.
DATE AD 1260 May 28
FELT IN EGYPT
SOURCE 20

263.
DATE AD 1261
MAG. ML 6.9
FELT IN LEBANON, ISRAEL
DETAILS AFFECTED LEBANESE COAST. 7 ISLANDS SANK BETWEEN ACRE & TRIPOLI
HAZARDS SUBSIDENCE OFF THE LEBANESE & ISRAELI COAST
SOURCE 12

264.
DATE AD 1261 Nov
FELT IN YEMEN A.R.
DETAILS INTENSITY AT SAN'A =7-8
SOURCE 1,2

265.
DATE AD 1262
FELT IN IRAQ
DETAILS INTENSITY AT MOSUL =8
SOURCE 1,5

266.
DATE AD 1262
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =9-10. AFFECTED ALEXANDRIA
SOURCE 1

267.
DATE AD 1263 Feb 21
FELT IN EGYPT
SOURCE 1,20

268.
DATE AD 1265
FELT IN YEMEN A.R.
DETAILS SHOCKS AT SAN'A
SOURCE 4

269.
DATE AD 1267 Oct
FELT IN JORDAN, ISRAEL ?
HAZARDS LANDSLIDE INTO THE RIVER JORDAN
SOURCE 7,12
COMMENT NO ACTUAL EARTHQUAKE DESCRIPTION

270.
DATE AD 1268
EPICENT. SEYHAN PROVINCE, SOUTHERN TURKEY
FELT IN TURKEY, SYRIA
DETAILS FELT IN ASIA MINOR. 60,000 DEAD IN CILICIA (SOUTHERN TURKEY). INTENSITY =9 IN TURKEY. VERY STRONG IN NORTH EAST SYRIA (15,000 DEAD)
SOURCE 19,27,31,38
COMMENT (19) CITES 2 SEPERATE EARTHQUAKES

271.
DATE AD 1270
FELT IN ARABIA
DETAILS AFFECTED THE TOWN OF AT'TAIF
SOURCE 1

272.
DATE AD 1274
FAULT NORTH LEVANT
MAG. 6.1
FELT IN SYRIA
SOURCE 12,19
COMMENT VERY UNCERTAIN EVENT

273.

DATE AD 1284
FELT IN SYRIA
DETAILS INTENSITY AT DAMASCUS =9-10
SOURCE 1

274.

DATE AD 1287 Mar-Apr
EPICENT. NORTH SYRIA
FAULT NORTH LEVANT
MAG. ML 7.3
FELT IN SYRIA, ISRAEL, TURKEY
DETAILS INTENSITY AT HAMA =8-9, AT LATAKIA =8 & AT SAFAD =8. ALSO AFFECTED ARMENIA
SOURCE 1,6,7,12,19

275.

DATE AD 1290
FELT IN ISRAEL, SYRIA, TURKEY
SOURCE 19

276.

DATE AD 1292
FELT IN SYRIA
SOURCE 19
COMMENT SAME AS 275?

277.

DATE AD 1293-1294
FELT IN EGYPT
SOURCE 2

278.

DATE AD 1293
FAULT DEAD SEA FAULT - ARAVA SECTION?
FELT IN ISRAEL, JORDAN
DETAILS INTENSITY AT RAMLA & KARAK =8. ALSO AFFECTED LOD, GAZA & QAQUN
SOURCE 1,2,6,7,14

279.

DATE	AD 1302 Aug-Sep
FELT IN	SYRIA, EGYPT
DETAILS	DAMASCUS VIOLENTLY SHAKEN. STRONG SHOCKS FELT DURING 20 DAYS IN SYRIA & EGYPT
HAZARDS	A SMALL TSUNAMI AT ALEXANDRIA, EGYPT
SOURCE	2,20

280.

DATE	AD 1303 Jul 8 (Aug 8)
EPICENT.	OFF ALEXANDRIA, EGYPT
INTENS.	11
MAG.	ML 7.6
FELT IN	EGYPT, SYRIA, ISRAEL, CYPRUS, LIBYA, TUNISIA, SICILY, CRETE, JORDAN
DETAILS	INTENSITY AT CAIRO =8-9, ALEXANDRIA =8, QUS =9, FAYUM REGION =8, DAMASCUS =8 & SAFAD =8. ALSO AFFECTED EL WASTA, ACRE, AMIR, ANTIOCH & GABES. DAMAGE WAS CAUSED IN RHODES & AT CANDIA ON CRETE. INTENSITY IN ISRAEL =6-7 & GREECE =7. THE EARTHQUAKE WAS SEVERE IN THE ADRIATIC. A TOTAL OF 10,000 PEOPLE WERE KILLED, & ACCORDING TO (28) SHOCKS WERE EXPERIENCED FOR SEVERAL WEEKS
HAZARDS	A TSUNAMI AFFECTED RHODES, CRETE, SYRIA & THE EGYPTIAN & ISRAELI COAST FROM ACRE TO ALEXANDRIA. ALEXANDRIA WAS SUBMERGED BY THE TSUNAMI & THE REMAINS OF PHAROS DESTROYED. THE NILE FLOODED TO QUS
SOURCE	1,2,6,7,8,9,12,13,20,21,22,30,31
COMMENT	THE EPICENTRE MAY NOT HAVE BEEN OFF THE EGYPTIAN COASTLINE, BUT FURTHER OUT INTO THE MEDITERRANEAN BASIN

281.
DATE AD 1303 Dec
EPICENT. OFF RHODES
INTENS. 10
MAG. ML 7.0
FELT IN ISRAEL, EGYPT, CRETE, GREECE
DETAILS A GREAT GENERAL SHOCK IN THE EASTERN MEDITERRANEAN
HAZARDS A TSUNAMI AFFECTED THE SOUTH WEST COAST OF THE PELOPONNESUS, THE ADRIATIC, RHODES, CRETE, ACRE & ALEXANDRIA
SOURCE 12,19,22

282.
DATE AD 1310
EPICENT. IRAN
MAG. M 5.3
FELT IN IRAQ
DETAILS MANY DEAD IN SULAYMANIYAH
SOURCE 5,16

283.
DATE AD 1312 May 1
EPICENT. SINAI
FAULT DEAD SEA
INTENS. 8
MAG. ML 5.8
FELT IN SINAI
DETAILS A FORESHOCK OCCURED ON Apr 30
HAZARDS LANDSLIDES IN SINAI
SOURCE 12

284.
DATE AD 1323
FELT IN SYRIA
DETAILS INTENSITY =7
SOURCE 1

285.

DATE	AD 1326
EPICENT.	OFF ALEXANDRIA, EGYPT
INTENS.	5
MAG.	4.8
FELT IN	EGYPT
DETAILS	THE ALEXANDRIA LIGHTHOUSE WAS SHAKEN. THE EARTHQUAKE WAS FELT IN MANY PLACES IN EGYPT
SOURCE	22

286.

DATE	AD 1339 Jan 13 - Feb 11
FAULT	NORTH LEVANT
MAG.	6.4
FELT IN	SYRIA, LEBANON, ISRAEL
DETAILS	INTENSITY AT TRIPOLI =8. THE CITY WAS DAMAGED
SOURCE	1,2,6,12,19
COMMENT	(7) CITES GEOLOGICAL EVIDENCE FOR AN EARTHQUAKE IN AD 1340 WITH ITS EPICENTRE ALONG THE DEAD SEA FAULT

287.

DATE	AD 1341 May
FELT IN	EGYPT
DETAILS	INTENSITY AT ALEXANDRIA =8-9
SOURCE	1

288.

DATE	AD 1343 Jan 1
FELT IN	SYRIA
DETAILS	INTENSITY AT MEMBIJ =8-9 & AT DAMASCUS =6. ALEPPO DAMAGED & 5,700 DEAD AT MEMBIJ
SOURCE	1,3,19
COMMENT	(12) CITES AN EVENT ON THE NORTH LEVANT FAULT (ML 6.2) IN AD 1344

289.

DATE	AD 1343 May - 1344 May
FELT IN	EGYPT, SYRIA
SOURCE	2,19
COMMENT	UNCERTAINTY CONCERNING THIS EVENT, BUT (13) CITES A LARGE EARTHQUAKE OFF MALTA ON Nov 24, 1343

290.

DATE	AD 1344 Oct 14
FELT IN	SYRIA, TURKEY, GREECE
DETAILS	NO INFORMATION CONCERNING ACTUAL EARTHQUAKE DAMAGE
HAZARDS	A TSUNAMI IN THE SEA OF MARMARA & ALONG THE THRACIAN COAST. CONSTANTINOPLE WAS INUNDATED
SOURCE	22,23

291.

DATE	AD 1347 Dec
FELT IN	EGYPT
DETAILS	INTENSITY AT CAIRO =6
SOURCE	1

292.

DATE	AD 1349 Nov
FELT IN	YEMEN A.R.
DETAILS	ZABID SHAKEN
SOURCE	4

293.

DATE	AD 1353 Oct
FELT IN	EGYPT
DETAILS	AFFECTED CAIRO
SOURCE	1

294.

DATE	AD 1355
FELT IN	ISRAEL, SYRIA
DETAILS	(7) CITES GEOLOGICAL EVIDENCE FOR AN EARTHQUAKE WITH ITS EPICENTRE ALONG THE DEAD SEA FAULT DURING THIS YEAR
SOURCE	6,7,19

295.

DATE	AD 1359
FELT IN	YEMEN A.R., YEMEN P.D.R.
DETAILS	A GREAT EARTHQUAKE AFFECTING ZABID, SAN'A & ADEN
SOURCE	4

296.
DATE AD 1364-1365
FELT IN EGYPT
DETAILS CAIRO SHAKEN
SOURCE 2

297.
DATE AD 1366 Oct
FELT IN ISRAEL
DETAILS AFFECTED SAFAD
SOURCE 1

298.
DATE AD 1373
FELT IN EGYPT
DETAILS A SLIGHT SHOCK WITH INTENSITY AT CAIRO =5
SOURCE 1

299.
DATE AD 1374
FELT IN ISRAEL, SYRIA
DETAILS (7) CITES GEOLOGICAL EVIDENCE FOR AN EARTHQUAKE WITH ITS EPICENTRE ALONG THE DEAD SEA FAULT DURING THIS YEAR
SOURCE 6,7,19

300.
DATE AD 1375
FELT IN EGYPT
DETAILS INTENSITY AT ALEXANDRIA =8
SOURCE 1

301.
DATE AD 1377 Jan-Feb
FELT IN EGYPT
DETAILS CAIRO SHAKEN
SOURCE 2

302.
DATE AD 1385 Sep 19 or 20
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =5
SOURCE 1,2

303.
DATE AD 1386 Jul 17
FELT IN EGYPT
DETAILS A SLIGHT EARTHQUAKE IN EGYPT
SOURCE 2

304.
DATE AD 1387 Sep
FELT IN YEMEN A.R., YEMEN P.D.R., ARABIA
DETAILS HAJAR DAMAGED
SOURCE 4

305.
DATE AD 1388 Dec 1389 - 1389 Dec
FELT IN IRAN, SYRIA
DETAILS AFFECTED ALEPPO. (1) & (2) CITE Jan/Feb 1389 FOR AN EARTHQUAKE WITH INTENSITY 9-10 AT NEYSHABUR, IRAN - MANY DIED, THIS BEING THE 7th TIME THE TOWN HAD BEEN SHAKEN
SOURCE 1,2,8,19,24

306.
DATE AD 1394 Mar-Apr
FELT IN YEMEN A.R.
DETAILS AFFECTED MAWZA (40 SHOCKS)
SOURCE 4

307.
DATE AD 1399 Sep 20
FELT IN SYRIA
DETAILS INTENSITY AT DAMASCUS =5
SOURCE 1

308.
DATE AD 1402 or 1403 Nov 16
MAG. ML 6.8
FELT IN LEBANON, SYRIA, ISRAEL
DETAILS INTENSITY IN ISRAEL =6-7. (13) CITES 1402 FOR AN EVENT THAT RUINED MANY TOWNS IN SYRIA
HAZARDS A TSUNAMI AFFECTED SYRIA & ASIA MINOR
SOURCE 6,12,13,30,38

309.
DATE AD 1403 Dec 19
FELT IN SYRIA
DETAILS AFFECTED ALEPPO
SOURCE 1,2

310.
DATE AD 1404 Feb 11
FELT IN SYRIA
DETAILS INTENSITY AT ALEPPO =9. THE EARTHQUAKE ALSO AFFECTED LATAKIA. (12) CITES AN EVENT ON THE NORTH LEVANT FAULT IN 1404, WITH ML =6.1
HAZARDS (29) CITES FAULTING AT SHUGHR, SYRIA IN ASSOCIATION WITH AN EARTHQUAKE ON Feb 22, 1404
SOURCE 1,3,19
COMMENT CONFUSION CONCERNING THE DATE & EPICENTRAL LOCATION

311.
DATE AD 1404 Nov 5-Dec 4
FELT IN SYRIA
DETAILS ALEPPO SHAKEN - POSSIBLY 3 SHOCKS
SOURCE 2,3

312.
DATE AD 1404 Dec 5
FELT IN SYRIA
DETAILS INTENSITY AT ALEPPO =7
SOURCE 1

313.
DATE AD 1407 Apr 9-May 8
FELT IN SYRIA
DETAILS ANTIOCH SHAKEN - MANY LIVES LOST
SOURCE 2

314.
DATE AD 1408 Dec 30
FELT IN SYRIA, LEBANON, TURKEY
DETAILS INTENSITY AT ANTIOCH =10-11 & AT ALEPPO =10. THE EARTHQUAKE ALSO AFFECTED TRIPOLI. MANY LIVES WERE LOST
HAZARDS A TSUNAMI AFFECTED LATAKIA. FAULTING OCCURRED AT ALEPPO
SOURCE 1,2,3

315.

DATE	AD 1421-1422
FELT IN	EGYPT
DETAILS	SLIGHT EARTHQUAKE AT CAIRO
SOURCE	2

316.

DATE	AD 1425 Jun-Jul
FELT IN	EGYPT
SOURCE	2

317.

DATE	AD 1426 Nov
FELT IN	BAHRAIN
DETAILS	INTENSITY =10-11
SOURCE	1

318.

DATE	AD 1427
FELT IN	YEMEN A.R.
DETAILS	SERIES OF SHOCKS AT ZABID
SOURCE	4

319.

DATE	AD 1434 Nov-Dec
FELT IN	EGYPT
DETAILS	AFFECTED CAIRO
SOURCE	2

320.

DATE	AD 1437 Nov 7
FELT IN	EGYPT
DETAILS	INTENSITY AT CAIRO =6
SOURCE	1

321.

DATE	AD 1438 Feb
FELT IN	EGYPT
DETAILS	INTENSITY AT CAIRO =6. A SLIGHT EARTHQUAKE
SOURCE	1,2

322.

DATE	AD 1456
FELT IN	IRAQ
DETAILS	BAGHDAD SHAKEN. ALSO AFFECTED BASRA & KUFA
SOURCE	5

323.

DATE	AD 1457
EPICENT.	NEAR ERZINCAN, TURKEY
FAULT	NORTH ANATOLIAN
MAG.	ML 7.6
FELT IN	SYRIA, ISRAEL, TURKEY
DETAILS	MOST OF ERZINCAN WAS DESTROYED. INTENSITY IN ISRAEL =8 OR ABOVE. INTENSITY IN TURKEY =10. 32,000 DEAD
SOURCE	1,2,12,16,19,30,31,38
COMMENT	(38) CITES THE DATE AS 1458

324.

DATE	AD 1458 Nov 8 - 1459 Oct 27
FELT IN	JORDAN
DETAILS	INTENSITY AT KARAK =8. 100 DEAD
SOURCE	1,2,6,31
COMMENT	(2) CITES THE DATE AS 1456+. (1) CITES IT AS 1459

325.

DATE	AD 1463
FELT IN	YEMEN A.R.
DETAILS	A SERIES OF SHOCKS WERE FELT AT ZABID
SOURCE	4

326.

DATE	AD 1476
FELT IN	EGYPT
DETAILS	A SLIGHT EARTHQUAKE WITH INTENSITY =6
SOURCE	1,2

327.

DATE	AD 1481 Mar
EPICENT.	TURKEY
FAULT	NORTH ANATOLIAN
MAG.	ML 7.7
FELT IN	TURKEY, SYRIA, ISRAEL
DETAILS	30,000 DEAD. (30) GIVES INTENSITY IN ISRAEL AS 8 OR ABOVE. INTENSITY IN TURKEY =10
SOURCE	6,12,30,31
COMMENT	(31) CITES THE DATE AS 1482

328.

DATE	AD 1481 Mar 15, May 3 & May 12
EPICENT.	NEAR RHODES
MAG.	ML 7.5
FELT IN	RHODES, CRETE, EGYPT, ISRAEL, TURKEY
DETAILS	DAMAGE IN TURKEY & CRETE
HAZARDS	(22) CITES A TSUNAMI ON May 3 THAT FLOODED RHODES TO A DEPTH OF 6 FEET AND PENETRATED 200 FEET INLAND
SOURCE	12,22
COMMENT	POSSIBLY SAME AS 327?

329.

DATE	AD 1481 Mar 18
FELT	EGYPT, ARABIA
DETAILS	INTENSITY AT CAIRO & MECCA =7
SOURCE	1,2,37
COMMENT	ACCORDING TO (37), THE EPICENTRE WAS SOUTH OF ALEXANDRIA. AN EPICENTRE IN THE RED SEA WOULD SEEM MORE LIKELY IF ARABIA WAS ALSO AFFECTED. ALTERNATIVELY, THIS EVENT COULD BE THE SAME AS 328

330.
DATE AD 1481 Jul
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =5
SOURCE 1

331.
DATE AD 1481 Oct 3
EPICENT. RHODES
FELT IN ISRAEL, LEBANON?
HAZARDS A TSUNAMI ON THE LEVANTINE COAST
SOURCE 12
COMMENT UNCERTAIN EVENT - PRECISE LOCATION UNKNOWN

332.
DATE AD 1483 Jun 15
FELT IN EGYPT
DETAILS A SLIGHT SHOCK IN EGYPT
SOURCE 2

333.
DATE AD 1484 Mar 29-Apr 27
FELT IN SYRIA
DETAILS 6 SHOCKS WERE FELT IN ALEPPO. AN EVENT IN April HAD INTENSITY =7
SOURCE 1,8,24

334.
DATE AD 1486
FELT IN IRAQ
DETAILS MOSUL SHAKEN 3 TIMES
SOURCE 5

335.
DATE AD 1490 May 6
FELT IN EGYPT
DETAILS INTENSITY =5
SOURCE 1

336.

DATE	AD 1491 Apr 25
EPICENT.	CYPRUS
INTENS.	9-10
MAG.	ML 6.7
FELT IN	EGYPT
DETAILS	ACCORDING TO (2), SLIGHT SHOCKS WERE FELT IN EGYPT FROM Apr 25-May 1
SOURCE	12
COMMENT	(38) CITES AN EARTHQUAKE AT COS IN THE AEGEAN SEA WHICH OCCURRED IN THIS YEAR. THIS IS PROBABLY THE SAME EVENT

337.

DATE	AD 1491 May 1
EPICENT.	LOWER EGYPT
FELT IN	EGYPT
DETAILS	DAMAGE IN LOWER EGYPT
SOURCE	12
COMMENT	PROBABLY PART OF 336

338.

DATE	AD 1494 Jul 1
EPICENT.	OFF IRAKLION, CRETE
INTENS.	11
MAG.	ML 8.0
FELT IN	ISRAEL, CRETE
DETAILS	AFFECTED IRAKLION - UNKNOWN DAMAGE
HAZARDS	A TSUNAMI AFFECTED JAFFA, ISRAEL & IRAKLION
SOURCE	12,22,31

339.

DATE	AD 1500
FELT IN	EGYPT
DETAILS	A SLIGHT EARTHQUAKE WITH INTENSITY =5
SOURCE	1,2

340.

DATE	AD 1502
FELT IN	YEMEN P.D.R.
DETAILS	INTENSITY =8
SOURCE	1

341.
DATE AD 1502-1503
FELT IN YEMEN A.R.
DETAILS A SERIES OF SHOCKS IN ZABID
SOURCE 4

342.
DATE AD 1503
EPICENT. IRAN
MAG. M 6.9
FELT IN IRAN, IRAQ
DETAILS AFFECTED MOSUL
SOURCE 5,16

343.
DATE AD 1504
FELT IN YEMEN A.R., SOMALIA
DETAILS INTENSITY AT ZABID =8 & AT ZAYLAH (SOMALIA) =9
SOURCE 1,4

344.
DATE AD 1505
FELT IN ISRAEL?
DETAILS (7) CITES GEOLOGICAL EVIDENCE OF AN EARTHQUAKE HAVING OCCURRED ALONG THE DEAD SEA FAULT. NO ACTUAL DAMAGE REPORTED
SOURCE 7
COMMENT UNCERTAIN EVENT

345.
DATE AD 1509
FELT IN YEMEN A.R.
DETAILS INTENSITY AT ZABID =5
SOURCE 1,4

346.
DATE AD 1510
EPICENT. MAWZA?
FELT IN YEMEN A.R.
DETAILS INTENSITY AT MAWZA =7. THE EARTHQUAKE ALSO AFFECTED ZABID
SOURCE 1,4

347.
DATE AD 1512 Apr 7
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =5-6
SOURCE 1

348.
DATE AD 1523 Apr 5
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =5
SOURCE 1

349.
DATE AD 1525 Apr 9
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =5
SOURCE 1

350.
DATE AD 1526 Jul 14
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =5
SOURCE 1

351.
DATE AD 1529 Nov 12
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =7
SOURCE 1

352.
DATE AD 1532 Jul 10
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =5
SOURCE 1

353.
DATE AD 1534
FELT IN ISRAEL
DETAILS AFFECTED JERUSALEM
HAZARDS ACCORDING TO (22) THERE MAY HAVE BEEN A TSUNAMI ALONG THE COAST OF ISRAEL BETWEEN GAZA & JAFFA. THIS IS NOT MENTIONED BY CONTEMPORARY WRITERS
SOURCE 6,7,19,22

354.

DATE	AD 1541
FELT IN	ISRAEL
DETAILS	SLIGHT IN JUDAEA
SOURCE	6

355.

DATE	AD 1546 Jan 14
EPICENT.	NEAR DAMIYE, JORDAN
FAULT	DEAD SEA
INTENS.	10-11
MAG.	ML 7.0
FELT IN	ISRAEL, JORDAN, SYRIA
DETAILS	AFFECTED JERUSALEM (12 DEAD), GAZA, RAMLE, JERICHO, TIBERIAS, HEBRON (16 DEAD & 70 INJURED), SALT, NABLUS (300-500 DEAD), KARAK, DAMASCUS, JAFFA & RAMA. THE INTENSITY OF THE EARTHQUAKE IN ISRAEL >=8
HAZARDS	A LANDSLIDE OF THE LISAN MARLS ABOVE JISRED DAMIYE BLOCKED THE RIVER JORDAN FOR 2 DAYS. A FAULT EXTENDED FROM DAMIYE TO THE DEAD SEA. A SEICHE OCCURRED IN THE DEAD SEA & A TSUNAMI AT JAFFA
SOURCE	6,7,9,12,14,19,22,23,30

356.

DATE	AD 1546 Mar 15
FELT IN	ISRAEL
DETAILS	THE EARTHQUAKE AFFECTED SAMARIA WITH PERIPHERAL EFFECTS IN JERUSALEM
SOURCE	6

357.

DATE	AD 1550
EPICENT.	TABRIZ, IRAN
FELT IN	IRAN, IRAQ
DETAILS	AFFECTED BAGHDAD & MOSUL. MANY DEAD
SOURCE	5,16,31

358.

DATE	AD 1573 Feb 4
FELT IN	EGYPT
DETAILS	INTENSITY AT CAIRO =7
SOURCE	1

359.
DATE AD 1576 Apr 21
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =7
SOURCE 1

360.
DATE AD 1577 Jan 28
EPICENT. NEAR CYPRUS
INTENS. 8-9
MAG. ML 6.0
FELT IN CYPRUS, ISRAEL, SYRIA, TURKEY
DETAILS INTENSITY IN ISRAEL =6-7
SOURCE 6,7,9,12,30

361.
DATE AD 1588 Jan 3
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =7-8
SOURCE 1

362.
DATE AD 1588 Jan 14
FELT IN EGYPT, ISRAEL, SINAI
DETAILS INTENSITY AT CAIRO =8 & AT EILAT =9
SOURCE 1,12

363.
DATE AD 1588 Apr 9
FELT IN EGYPT
DETAILS INTENSITY AT CAIRO =9
SOURCE 1

364.
DATE AD 1605 Jan 8
FELT IN SINAI
SOURCE 12

365.
DATE AD 1608 Dec 14
FELT IN SINAI
SOURCE 12

366.
DATE AD 1613
FELT IN YEMEN P.D.R.
DETAILS A GREAT EARTHQUAKE WITH OFFSHORE EPICENTRE
SOURCE 4

367.
DATE AD 1613
FELT IN EGYPT
SOURCE 1
COMMENT (31) CITES A LARGE EARTHQUAKE WHICH OCCURRED IN THE CRETE AREA IN THIS YEAR. THIS AFFECTED IRAKLION CAUSING MANY DEATHS

368.
DATE AD 1616 Aug 27
FAULT NORTH LEVANT
MAG. ML 6.1
FELT IN SYRIA
DETAILS DAMAGE IN ALEPPO & ANTIOCH
SOURCE 12,14

369.
DATE AD 1630
FELT IN ARABIA?
DETAILS AFFECTED MECCA & MEDINA
SOURCE 13
COMMENT SOME DOUBT EXPRESSED CONCERNING THIS EVENT

370.
DATE AD 1640
FAULT NORTH LEVANT
MAG. ML 6.3
FELT IN SYRIA, IRAN
DETAILS AFFECTED TABRIZ & DAMASCUS
SOURCE 12,13,14,19
COMMENT SAME AS 371?

371.
DATE AD 1641 Feb 5
EPICENT. IRAN
MAG. M 6.8
FELT IN IRAQ, IRAN
DETAILS BAGHDAD SHAKEN WITHOUT DAMAGE. TABRIZ & KURDISTAN WERE BADLY AFFECTED. 30,000 DEAD
SOURCE 5,13,16,31,38

372.
DATE AD 1644 Sep 22
FELT IN YEMEN A.R.
DETAILS AN EARTHQUAKE TO THE EAST OF SA'DAH
HAZARDS ROCKFALLS OCCURRED IN ASSOCIATION WITH THIS EVENT
SOURCE 4

373.
DATE AD 1647
FELT IN YEMEN A.R.
DETAILS AFFECTED SAN'A & REGION
SOURCE 4

374.
DATE AD 1656 Feb
FAULT NORTH LEVANT
INTENS. 10
MAG. 7.0
FELT IN LEBANON, SYRIA, ISRAEL
DETAILS TRIPOLI DESTROYED
SOURCE 6,12,13,19

375.
DATE AD 1666 Sep 22
FAULT NORTH LEVANT
MAG. 6.4
FELT IN SYRIA
DETAILS ALEPPO & 44 OTHER TOWNS WERE SERIOUSLY DAMAGED
SOURCE 12,19

376.

DATE	AD 1666 Nov
EPICENT.	ZEBAR, IRAQ
MAG.	M 6.5
FELT IN	IRAQ, ISRAEL, TURKEY
DETAILS	STRONG AT MOSUL. 5 CITIES/TOWNS & 45 VILLAGES WERE DESTROYED. THE EARTHQUAKE AFFECTED ARMENIA & MENSAL IN ASSYRIA
HAZARDS	A 2 km LONG FAULT IN THE EPICENTRAL REGION
SOURCE	5,13,16,18,29,38

377.

DATE	AD 1667 Mar
FELT IN	YEMEN A.R.
DETAILS	AFFECTED SAN'A & MOST OF YEMEN
SOURCE	4

378.

DATE	AD 1668 Sep 13
FELT IN	ASIA MINOR, ISRAEL
DETAILS	AFFECTED CAESAREA
SOURCE	13
COMMENT	ACCORDING TO (31) AN EARTHQUAKE OCCURRED IN TURKEY ON Jul 10 OF THIS YEAR. THIS HAD INTENSITY =10 & KILLED 17,500

379.

DATE	AD 1672
FELT IN	SINAI
SOURCE	12

380.

DATE	AD 1674 Aug
FELT IN	YEMEN A.R.
DETAILS	AFFECTED DAWRAN (30 SHOCKS IN ALL)
SOURCE	4

381.

DATE	AD 1675
FELT IN	YEMEN A.R.
DETAILS	A MAJOR EARTHQUAKE AFFECTING DAWRAN & SAN'A
HAZARDS	ROCKFALLS OCCURRED FROM JABAL DAWRAN
SOURCE	4

382.

DATE	AD 1680
FELT IN	IRAQ
DETAILS	AFFECTED RAWAH ON THE EUPHRATES
SOURCE	5,18
COMMENT	(31) & (38) CITE AN EARTHQUAKE THAT OCCURRED IN YEREVAN, TURKEY ON 4/6/1679. THIS AFFECTED TURKEY & NORTH IRAQ. IT CAUSED EXTREME DAMAGE AT DVINA & KILLED 7,600

383.

DATE	AD 1687 Mar
EPICENT.	OFF ALEXANDRIA, EGYPT (31.0°N 29.5°E)
INTENS.	6
MAG.	ML 4.5
FELT IN	EGYPT
DETAILS	VIBRATIONS IN ALEXANDRIA FOR 10-12 DAYS
SOURCE	21,37

384.

DATE	AD 1693
FELT IN	IRAQ
DETAILS	NO MENTION OF AN EARTHQUAKE EVENT
HAZARDS	A LANDSLIDE OCCURRED IN THE JEBAL SINJAR AREA OF IRAQ
SOURCE	5

385.

DATE	AD 1698 Oct 2
EPICENT.	ROSETTA, EGYPT
INTENS.	6
MAG.	5.5
FELT IN	EGYPT
DETAILS	AFFECTED ROSETTA & ALEXANDRIA. FELT ALONG THE NILE VALLEY. IN THE NILE DELTA IT WAS FELT IN THE AREA BORDERED BY BEHEIRA, ALEXANDRIA, KAFR EL SHEIKH & GHARBIYA PROVINCES. INTENSITY AT IDFINA =6
SOURCE	20,21,28

386.

DATE	AD 1702
FELT IN	IRAQ
DETAILS	AFFECTED BAGHDAD
SOURCE	5

387.

DATE	AD 1705
FELT IN	SYRIA
DETAILS	AFFECTED DAMASCUS
SOURCE	1

388.

DATE	AD 1710
FELT IN	ISRAEL?
DETAILS	(7) CITES GEOLOGICAL EVIDENCE FOR AN EARTHQUAKE ALONG THE DEAD SEA FAULT. NO ACTUAL EARTHQUAKE DAMAGE DESCRIBED
SOURCE	7

389.

DATE	AD 1714
EPICENT	IRAN
FELT IN	IRAQ
DETAILS	ARBIL SHAKEN - NOT STRONG
SOURCE	5,16

390.

DATE	AD 1719 Mar 6
FAULT	NORTH LEVANT
MAG.	ML 6.2
FELT IN	ASIA MINOR, SYRIA
DETAILS	DAMAGING AT ALEPPO WHERE 100 PEOPLE WERE KILLED & 200 HOUSES DESTROYED. LIMITED DAMAGE AT IZMIR
SOURCE	12,13,25
COMMENT	(38) CITES AN EVENT THAT OCCURRED ON May 25 OF THIS YEAR AFFECTING IZMIT & ISTANBUL

391.

DATE	AD 1726 Apr 15
FAULT	NORTH LEVANT
MAG.	ML 6.1
FELT IN	TURKEY, SYRIA
DETAILS	AFFECTED ALEPPO & ALEXANDRETTA (ISKENDERUN)
SOURCE	12,13,19

392.
DATE AD 1734 Sep
EPICENT. $30.8^{O}N$ $31.0^{O}E$
FELT IN EGYPT
MAG. 6.0
INTENS. 8
DETAILS FELT ACROSS THE NILE DELTA BETWEEN THE DAMIETTA & ROSETTA BRANCHES OF THE RIVER
SOURCE 37

393.
DATE AD 1735 Nov 23
FELT IN SYRIA
DETAILS INTENSITY AT DAMASCUS =5
SOURCE 1

394.
DATE AD 1746 Jul 5
FELT IN SYRIA
DETAILS INTENSITY AT DAMASCUS =5
SOURCE 1

395.
DATE AD 1752 Jul 21
EPICENT. OFF LATAKIA, SYRIA
INTENS. 10
MAG. ML 7.0
FELT IN TURKEY, SYRIA, ISRAEL, LEBANON
DETAILS DESTRUCTIVE EARTHQUAKE WHICH KILLED 20,000. THE EARTHQUAKE AFFECTED THE COASTS OF ISRAEL, LEBANON & SYRIA DESTROYING TRIPOLI. INTENSITY IN ISRAEL =8 OR ABOVE
HAZARDS A TSUNAMI AFFECTED THE SYRIAN COAST
SOURCE 6,9,12,22,30,31

396.
DATE AD 1753 Dec 18
FELT IN SYRIA
DETAILS INTENSITY AT DAMASCUS =7
SOURCE 1

397.

DATE	AD 1754 Sep
EPICENT.	TANTA REGION, LOWER EGYPT
INTENS.	8
MAG.	6.0
FELT IN	EGYPT
DETAILS	DESTRUCTIVE EARTHQUAKE. 2/3rds OF THE BUILDINGS IN CAIRO WERE DAMAGED & THOUSANDS OF PEOPLE WERE KILLED. THE EARTHQUAKE WAS FELT OVER AN AREA OF 150,000 sq km. INTENSITY OF SHAKING =8 IN A LIMITED AREA OF GHARBIYA PROVINCE, & 7 ACROSS THE REMAINDER OF THE NILE DELTA & CAIRO. 40,000 DEAD & SEVERE DAMAGE CAUSED
SOURCE	12,13,21,28,31

398.

DATE	AD 1756 Aug 31
FELT IN	SYRIA
DETAILS	AFFECTED DAMASCUS
SOURCE	1

399.

DATE	AD 1758 Feb 3, Mar 8 & Apr
FELT IN	SYRIA
DETAILS	AFFECTED DAMASCUS
SOURCE	UNCERTAIN

400.

DATE	AD 1759 Oct 30
EPICENT.	SAFED, ISRAEL (33.3°N 35.7°E)
FAULT	DEAD SEA
INTENS.	9
MAG.	ML 6.5
FELT IN	ISRAEL, SYRIA, LEBANON, JORDAN, TURKEY
DETAILS	165 DEAD AT SAFED. TIBERIAS WAS DAMAGED & THE CITY WALL THROWN DOWN. AT DAMASCUS THE INTENSITY =10-11. QUNEITRA, COELE, BA'ALBEK, ALEPPO, SIDON (INT.=7) & TRIPOLI WERE ALL AFFECTED. 20,000 DEAD IN TOTAL
HAZARDS	A TSUNAMI AT ACRE FLOODED THE STREETS TO A DEPTH OF 8'. IT ALSO AFFECTED THE LEBANESE COAST. A SEICHE OCCURRED IN THE SEA OF GALILEE (LAKE TIBERIAS) AFFECTING TIBERIAS
SOURCE	1,6,9,12,17,19,22,30,31,38

401.

DATE	AD 1759 Nov 19
FELT IN	SYRIA
DETAILS	AFFECTED HOMS
SOURCE	12

402.

DATE	AD 1759 Nov 25
EPICENT.	NIHA, LEBANON (33.8°N 36.2°E)
FAULT	BEKA'A
INTENS.	10-11
MAG.	ML 6.8
FELT IN	SYRIA, LEBANON, ISRAEL
DETAILS	AFFECTED SAFED (INT.=8), ALEPPO, TRIPOLI & THE VALLEY OF BA'ALBEK. PART OF DAMASCUS WAS DESTROYED. DAMAGE EXTENDED AS FAR NORTH AS ALEPPO & AS FAR SOUTH AS JAFFA. THE COAST OF SYRIA WAS AFFECTED. THOUSANDS DIED IN THE BEKA'A VALLEY. A TOTAL OF 30,000 DEAD
HAZARDS	FAULTING OCCURRED AT NIHA, LEBANON. LENGTH OF FAULT =5km
SOURCE	6,12,13,17,25,29,31
COMMENT	(13) CITES THE DATE AS Nov 26

403.

DATE	AD 1759 Nov 28
FELT IN	ISRAEL?
DETAILS	NO REFERENCE TO ACTUAL EARTHQUAKE DAMAGE
SOURCE	6,13
COMMENT	UNCERTAIN EVENT

404.

DATE	AD 1759 Dec 7
FELT IN	SYRIA
DETAILS	AFFECTED ANTIOCH
HAZARDS	(22) SUGGESTS THERE MAY HAVE BEEN A TSUNAMI IN THE EASTERN MEDITERRANEAN IN Dec OF THIS YEAR
SOURCE	6

405.
DATE AD 1760
FELT IN SYRIA
DETAILS SEVERAL SHOCKS FELT
HAZARDS (22) SUGGESTS THERE MAY HAVE BEEN A TSUNAMI IN THE EASTERN MEDITERRANEAN IN Feb OF THIS YEAR & ALSO ON Mar 1 & Mar 8
SOURCE 19

406.
DATE AD 1764
FELT IN SYRIA, LEBANON
DETAILS AFFECTED ALEPPO & TRIPOLI
SOURCE 19

407.
DATE AD 1764
FELT IN IRAQ
DETAILS SLIGHT SHOCK IN MOSUL
SOURCE 5

408.
DATE AD 1769 May 1
EPICENT. IRAN
FELT IN IRAQ
DETAILS 2,000 HOUSES DESTROYED IN BAGHDAD
SOURCE 5,18

409.
DATE AD 1778
FELT IN SYRIA
DETAILS AFFECTED ALEPPO
SOURCE 19

410.
DATE AD 1778 Jun 22 or 23
FELT IN EGYPT
DETAILS EARTHQUAKE NEAR NAG 'HAMMADI
SOURCE 12

411.
DATE AD 1781
FELT IN IRAQ, IRAN
DETAILS AFFECTED MOSUL. 80 DEAD
HAZARDS FAULTING IN THE EPICENTRAL REGION
SOURCE 5

412.
DATE AD 1783
FELT IN SYRIA
DETAILS LIGHT SHOCK AT ALEPPO
SOURCE 19

413.
DATE AD 1788 Nov
EPICENT. NEAR AL HUDAYDAH, YEMEN A.R.
FELT IN YEMEN A.R., ARABIA
DETAILS EARTHQUAKE NEAR AL HUDAYDAH. AFFECTED BAYT QASR & BAYT HINDI. STRONGLY FELT FROM MUKHA IN THE SOUTH TO ABU ARISH (ARABIA) IN THE NORTH
SOURCE 4

414.
DATE AD 1789
FELT IN YEMEN A.R.
DETAILS AFFECTED MUKHA
SOURCE 4

415.
DATE AD 1795
FELT IN SYRIA
DETAILS AFFECTED ALEPPO
SOURCE 19

416.
DATE AD 1796 Apr 26
FAULT NORTH LEVANT
MAG. 6.1
FELT IN SYRIA
DETAILS MAJOR DAMAGE IN THE REGION OF LATAKIA WITH 1,500 DEAD
SOURCE 12,13,25,27,38
COMMENT (12) CITES THE DATE AS Apr 25 WHEREAS (13) & (38) CITE Feb 26

417.

DATE	AD 1801
FELT IN	SINAI
SOURCE	12

418.

DATE	AD 1802
EPICENT.	34.0°N 36.2° E
FAULT	BEKA'A
INTENS.	8-9
MAG.	ML 6.2
FELT IN	LEBANON, SYRIA, ISRAEL
DETAILS	AFFECTED THE LIBAN VALLEY OF BA'ALBEK - GREAT DAMAGE AT BA'ALBEK. SLIGHT DAMAGE IN ISRAEL
SOURCE	6,12,17,19

419.

DATE	AD 1802
EPICENT.	IRAN
FELT IN	IRAQ
DETAILS	AFFECTED SULAYMANIYAH
SOURCE	5,16

420.

DATE	AD 1805 Jul 2
FELT IN	EGYPT
DETAILS	4 SHOCKS DURING THE NIGHT - NO PRECISE LOCATION GIVEN
SOURCE	20

421.

DATE	AD 1810 Feb 16
EPICENT.	SEA OF CRETE (35.5°N 25.0°E)
INTENS.	11
MAG.	ML 7.8
FELT IN	ISRAEL, NORTH AFRICA, CYPRUS, CRETE
DETAILS	SEVERE AT IRAKLION, CRETE. 2,000 DEAD. INTENSITY ON CYPRUS =5
SOURCE	17,31,38

422.

DATE	AD 1811
EPICENT.	NEAR SIWA OASIS, EGYPT (29.1°N 25.9°E)
MAG.	5.5
INTENS.	7
FELT IN	EGYPT
DETAILS	A MAXIMUM INTENSITY OF 7 WAS OBSERVED IN SIWA. FELT OVER A LIMITED AREA IN THE WESTERN DESERT
SOURCE	28,37

423.

DATE	AD 1822 Aug 13
EPICENT.	LOWER ORONTES VALLEY NEAR ALEPPO, SYRIA
FAULT	NORTH LEVANT
INTENS.	10-11
MAG.	ML 7.1
FELT IN	SYRIA, LEBANON, ISRAEL, CYPRUS, EGYPT, TURKEY
DETAILS	EARTHQUAKE WITH EPICENTRE IN THE REGION BETWEEN ALEPPO & JISR ESH SHUGHUR. INTENSITY AT ANTIOCH & ALEPPO =10-11 (ALEPPO WAS DESROYED). 8,000-20,000 DEAD. 17,000 HOUSES DESTROYED. ALSO AFFECTED LATAKIA AND PERIPHERAL EFFECTS WERE FELT AT JERUSALEM. IN TURKEY THE INTENSITY =10. THE EARTHQUAKE WAS ALSO FELT AT ALEXANDRIA ACCORDING TO (13) THOUGH THIS MIGHT BE DUE TO CONFUSION WITH ALEXANDRETTA (ISKENDERUN)
HAZARDS	TSUNAMI AT ISKENDERUN & AT BEIRUT
SOURCE	3,12,13,25,31,38
COMMENT	(17) CITES THE DATE AS Aug 23 WHEREAS (31) CITES Jul 7

424.

DATE	AD 1822 Sep 5
FAULT	NORTH LEVANT
MAG.	ML 6.6
FELT IN	SYRIA, ISRAEL, ASIA MINOR, TURKEY, CYPRUS
DETAILS	BETWEEN 20,000 & 22,000 DEAD (MORTALITY FIGURES POSSIBLY CONFUSED WITH THE PREVIOUS EVENT). AFFECTED ANTIOCH, LATAKIA & DAMASCUS. INTENSITY IN TURKEY =10
SOURCE	3,6,12,13,19,31
COMMENT	POSSIBLY SOME CONFUSION BETWEEN REPORTS OF THIS EARTHQUAKE AND 423

425.

DATE	AD 1823
FELT IN	SYRIA
DETAILS	FELT AT ANTIOCH
SOURCE	19
COMMENT	(31) CITES AN EVENT FOR Jun 19, 1823 WITH INTENSITY =11 IN GREECE

426.

DATE	AD 1830
FELT IN	SYRIA
DETAILS	AFFECTED ALEPPO
SOURCE	19

427.

DATE	AD 1831
FELT IN	SYRIA
DETAILS	AFFECTED ALEPPO
SOURCE	19
COMMENT	SAME AS ABOVE?

428.

DATE	AD 1834 May 23
EPICENT.	EAST OF LISAN, JORDAN
FAULT	DEAD SEA FAULT (31.3^{o}N 35.6^{o}E)
INTENS.	9
MAG.	ML 6.3
FELT IN	JORDAN, ISRAEL, ASIA MINOR
DETAILS	A STRONG EVENT AFFECTING TIBERIAS, ACRE, JERUSALEM (DAMAGED), BETHLEHEM (MUCH DAMAGE - MANY FATALITIES), ASCALON, GAZA & DEIT MAR SABA MONASTERY (SLIGHT DAMAGE). NABLUS, KERAK & THE REGION OF MOAB WERE ALSO DAMAGED. INTENSITY IN ISRAEL =6-7
HAZARDS	POSSIBLE DOWN-FAULTING OF THE DEAD SEA FLOOR
SOURCE	6,9,12,13,17,19,30

429.

DATE	AD 1837 Jan 1
EPICENT.	EAST OF SAFED, ISRAEL (33.0^{o}N 35.5^{o}E)
FAULT	DEAD SEA FAULT
INTENS.	9
MAG.	ML 6.4
FELT IN	ISRAEL, LEBANON, JORDAN, SYRIA
DETAILS	INTENSITY AT EL-JISH =SM11 (235 DEAD), QADDITA =SM9-10, EYN ZEITIM =SM11, SAFED =SM11 (5,000 DEAD), TIBERIAS =SM10 (700 DEAD), LUBYA =SM8 (143 DEAD), SEJERA =SM9-10, KAFR KANNA =SM5, REYNA =SM10-11, NAZARETH =SM7 (5 DEAD), ZIPPORI =SM4-5. ACCORDING TO (25), 4393 DIED IN THE TIBNIN-SAFED REGION. SEVERAL PEOPLE WERE KILLED AT ACRE. THE EARTHQUAKE ALSO AFFECTED JERUSALEM & BETHLEHEM & CAUSED MODERATE DAMAGE IN JAFFA. DAMAGE WAS EXPERIENCED IN DAMASCUS & BEIRUT. AT SIDON MANY HOUSES WERE DAMAGED & A FEW PEOPLE WERE KILLED. THERE WAS DAMAGE TO THE CITY WALL AT TYRE WHERE 12 PEOPLE WERE KILLED & 30 INJURED. TRIPOLI WAS ALSO AFFECTED & THERE WERE SEVERAL PEOPLE KILLED AT NABLUS. THE INTENSITY OF THE EARTHQUAKE IN ISRAEL WAS >=8
HAZARDS	FAULTING (LENGTH =15km) & POSSIBLY A LANDSLIDE AT SAFED. A SEICHE AFFECTED TIBERIAS & A TSUNAMI WAS RECORDED ALONG THE EASTERN MEDITERRANEAN COAST FROM ISRAEL TO SYRIA
SOURCE	6,9,12,17,19,22,25,27,29,30,31,38

430.

DATE	AD 1837 Feb 24
FELT IN	ISRAEL
HAZARDS	A SEICHE OCCURRED ON Feb 24 & May 22 IN LAKE TIBERIAS
SOURCE	22
COMMENT	NO ACTUAL EARTHQUAKE DESCRIBED

431.

DATE	AD 1838
FELT IN	ISRAEL
DETAILS	AFFECTED JUDAEA & JAFFA. 3,000 DEAD
SOURCE	6,19

432.
DATE AD 1839
FELT IN SINAI
SOURCE 12

433.
DATE AD 1844-1845
FELT IN ISRAEL
DETAILS 2 SLIGHT SHOCKS OCCURRED DURING THIS YEAR
SOURCE 6

434.
DATE AD 1844 May 12 (and 13)
EPICENT. IRAN
MAG. M 6.4
FELT IN IRAQ
SOURCE 13,16
COMMENT ACCORDING TO (13) AND (31) AN EARTHQUAKE ALSO OCCURRED AT ERZERUM IN TURKEY ON May 12. THIS EVENT HAD AN INTENSITY =9 AND KILLED 200 (31)

435.
DATE AD 1846 Mar 28
EPICENT. CRETE AREA (36.0°N 25.0°E)
INTENS. 10
MAG. ML 7.6
FELT IN CRETE, ISRAEL, EGYPT, SYRIA, GREECE
DETAILS FELT ESPECIALLY IN JERUSALEM & CAIRO
SOURCE 12,13,17,20

436.
DATE AD 1847
FELT IN EGYPT
DETAILS AFFECTED CAIRO
SOURCE 13
COMMENT SAME AS 437?

437.
DATE AD 1847 Aug 7
EPICENT. NEAR EL FAYUM, EGYPT (29.5°N 30.5°E)
INTENS. 9-10
MAG. ML 6.8
FELT IN EGYPT
DETAILS AT EL FAYUM THE INTENSITY =9-10 (85 DEAD, 62 INJURED, 3000 HOUSES & 42 MOSQUES DESTROYED). HEAVY DAMAGE OCCURRED IN THE NILE VALLEY AS FAR AS ASYUIT. IN CAIRO 100 PEOPLE WERE KILLED & THOUSANDS OF HOUSES DESTROYED. IN MID EGYPT 27 PEOPLE DIED. THOUSANDS OF PEOPLE WERE INJURED IN TOTAL. AN AFTERSHOCK OCCURRED ON Aug 10
SOURCE 12,13,20,21,25,28,31
COMMENT (21) & (28) GIVE THE EPICENTRAL INTENSITY AS 8 & THE MAGNITUDE AS 6.2

438.
DATE AD 1854
FELT IN SYRIA, LEBANON
DETAILS AFFECTED ANTIOCH, ALEPPO, SUEIDIJE & BEIRUT
SOURCE 19
COMMENT SIMILAR TO REPORTS FOR AN EVENT IN 1859

439.
DATE AD 1854 Jan 3
FELT IN EGYPT, SUDAN
DETAILS AFFECTED UPPER EGYPT & KHARTOUM
SOURCE 20

440.
DATE AD 1856 Oct 12
EPICENT. NORTH EAST OF CRETE (35.5°N 26.0°E)
INTENS. 11
MAG. ML 8.0
FELT IN SYRIA, EGYPT, ISRAEL, LEBANON, ITALY, GREECE, TURKEY, ASIA MINOR, CYPRUS, CRETE
DETAILS SLIGHT DAMAGE IN NORTH SYRIA, NORTH ISRAEL & THE NILE DELTA. TIBERIAS & CAIRO WERE ESPECIALLY AFFECTED. INTENSITY IN CYPRUS =4. ON CRETE SEVERE DAMAGE WAS CAUSED IN IRAKLION & 538 WERE KILLED. AN AFTERSHOCK OCCURRED ON THE SAME DAY KILLING 20. (cont.)

HAZARDS   A TSUNAMI AT HAIFA IN ISRAEL & ALSO ALONG THE LEBANESE COAST
SOURCE   6,12,13,17,20,30,31
COMMENT   (38) CITES THE EPICENTRE AS RHODES, AEGEAN SEA

441.
DATE   AD 1859
FELT IN   SYRIA, LEBANON
DETAILS   AFFECTED SUEDIDIJE, ANTIOCH, ALEPPO & BEIRUT
SOURCE   19
COMMENT   THERE WERE SEVERE EVENTS IN TURKEY ON Jun 2 (NEAR ERZURUM) AND Aug 21 OF THIS YEAR (31,38)

442.
DATE   AD 1859 Jan
FELT IN   YEMEN A.R, YEMEN P.D.R.
DETAILS   AFFECTED MUKHA & THE SURROUNDING AREAS. ALSO AFFECTED ADEN
SOURCE   4

443.
DATE   AD 1859 Oct 24
FELT IN   ISRAEL
DETAILS   AFFECTED JERUSALEM WITH INTENSITY =SM5-6
SOURCE   6

444.
DATE   AD 1861 Sep 24
FELT IN   RED SEA
DETAILS   SHOCKS FELT IN THE RED SEA
SOURCE   20

445.
DATE   AD 1862 Nov 9
FELT IN   IRAQ
DETAILS   AFFECTED KIRKUK
SOURCE   5

446.

DATE	AD 1863 Apr 22
EPICENT.	RHODES (36.5°N 28.0°E)
INTENS.	11
MAG.	ML 7.5
FELT IN	ISRAEL, EGYPT, TURKEY, RHODES, KOS
DETAILS	AFFECTED JERUSALEM, CAIRO & ALEXANDRIA. ALSO SMYRNA (IZMIR). MODERATE DAMAGE WAS CAUSED
SOURCE	12,17,20 31,38
COMMENT	(31) CITES THE MAGNITUDE AS 6.7

447.

DATE	AD 1863 Sep 24
FELT IN	ISRAEL
DETAILS	INTENSITY AT JERUSALEM =SM 5
SOURCE	6,19

448.

DATE	AD 1864
FELT IN	ISRAEL
DETAILS	AFFECTED JERUSALEM
SOURCE	19

449.

DATE	AD 1864 Dec 7
EPICENT.	IRAN
MAG.	M 6.4
SOURCE	16

450.

DATE	AD 1864 Dec 20
EPICENT.	ZORBAT, IRAQ (33.0N 46.0E)
FELT IN	IRAQ, ASIA MINOR
DETAILS	100 DEAD AT ZURBATIYAH. BADRAH, MANDALI, TURSAQ & JASSAN WERE HEAVILY DAMAGED. ALSO AFFECTED AL KUT & VILLAGES TO THE NORTH EAST. SHOCKS WERE FELT IN BAGHDAD & BASRA
HAZARDS	FAULTING AT ZORBAT (LENGTH =2+ km, VERTICAL DISPLACEMENT =50 cm)
SOURCE	5,29

451.
DATE AD 1864 Dec 25
FELT IN IRAQ
DETAILS SHOCKS FELT IN BAGHDAD & BASRA. SOME DAMAGE AT AL KUT
SOURCE 5

452.
DATE AD 1865 Feb 4
FELT IN IRAQ
DETAILS HEAVIEST SHAKING AT SUKEASH & SCHEJUK. THE EARTHQUAKE WAS DAMAGING IN THE ZURBATIYAH AREA, BUT LESS STRONG IN BAGHDAD & BASRA
SOURCE 5,18,25

453.
DATE AD 1865 Feb 8
FELT IN IRAQ
DETAILS AFFECTED THE REGION AROUND TURSAQ & JASSAN
HAZARDS LANDSLIDES & GROUND SUBSIDENCE IN THE HILLS NORTH OF AL KUT, IRAQ
SOURCE 5

454.
DATE AD 1866 Feb 4
EPICENT. IONIAN ISLS (38.2°N 20.2°E)
INTENS. 11
MAG. ML 7.9
SOURCE 17
COMMENT NO INFORMATION AVAILABLE CONCERNING DAMAGE EXPERIENCED

455.
DATE AD 1866 Jul
FELT IN IRAQ
DETAILS FELT BETWEEN THE EUPHRATES & TIGRIS RIVERS ESPECIALLY AT BAGHDAD
SOURCE 13
COMMENT AN EARTHQUAKE EVENT WITH INTENSITY =9 OCCURRED IN TURKEY ON July 22 ACCORDING TO (31). THE EPICENTRE WAS AT 38.5°N 40.1°E

456.
DATE AD 1866 Oct 9
EPICENT. DJEBEL DUMBEIR, SUDAN
FELT IN SUDAN
DETAILS AN EARTHQUAKE IN THE DJEBEL DUMBEIR AREA KILLED 2 PEOPLE
HAZARDS FAULTING AT DJEBEL DUMBEIR
SOURCE 25

457.
DATE AD 1867 Apr 14
EPICENT. NEAR MANDALI-JALULA, IRAQ
FELT IN IRAQ
DETAILS A MODERATE EARTHQUAKE WHICH DAMAGED BAGHDAD
SOURCE 5,18

458.
DATE AD 1867 Sep 19-20
EPICENT. 36.5°N 22.25°E
INTENS. 10
FELT IN GREECE, EGYPT, CRETE, ITALY
DETAILS AFFECTED THE WEST COAST OF ALEXANDRIA IN EGYPT AND IRAKLION ON CRETE
SOURCE 20

459.
DATE AD 1868
FELT IN ISRAEL
DETAILS AFFECTED JERUSALEM
SOURCE 19

460.
DATE AD 1868 Feb 20
FELT IN EGYPT
DETAILS SHOCKS WERE FELT AT NIGHT IN ALEXANDRIA & CAIRO
SOURCE 20

461.
DATE AD 1870 Jun 24
EPICENT. OFF ALEXANDRIA, EGYPT (32.0°N 30.0°E)
INTENS. 10-11
MAG. ML 7.2
FELT IN EGYPT, GREECE, SUDAN, YEMEN P.D.R., TURKEY, SYRIA, ISRAEL, ALBANIA, MALTA, SOUTHERN ITALY (cont.)

DETAILS	FELT WIDELY IN EGYPT & DIFFERENT LOCALITIES OF GREECE & SOUTHERN TURKEY. FELT ALONG THE RED SEA NEARLY TO ADEN. DAMAGE AT ALEXANDRIA (INT. =7) & ISMAILIYA. AFFECTED GAZA, NAZARETH, JERUSALEM & DAMASCUS
HAZARDS	TSUNAMI AT ALEXANDRIA
SOURCE	12,13,17,20,22,28,38
COMMENT	MAGNITUDE MAY HAVE BEEN 6.5. ACCORDING TO (38), THE EPICENTRE WAS NEAR TO RHODES

462.

DATE	AD 1872 Apr 3
EPICENT.	NEAR SAMANDAG, SYRIA (36.2^{O}N 36.2^{O}E)
FAULT	NORTH LEVANT
INTENS.	10-11
MAG.	ML 7.3
FELT IN	SYRIA, RHODES, EGYPT, ISRAEL, LEBANON, IRAQ?
DETAILS	ANTIOCH DESTROYED & MAJOR DAMAGE IN THE REGION OF HARIM & ALEPPO (APPROX 1,800 DEAD, 3,200 HOUSES DESTROYED). ALSO AFFECTED DAMASCUS & BEIRUT. ACCORDING TO (20), MESOPOTAMIA WAS ALSO AFFECTED. AFTERSHOCKS OCCURRED ON Apr 10 & May 25
SOURCE	3,12,13,17,19,20,25,31,38
COMMENT	(17) & (20) CITE THE DATE OF THE MAJOR EVENT AS Apr 2

463.

DATE	AD 1873
FELT IN	YEMEN A.R.
DETAILS	AN EARTHQUAKE IS REPORTED TO HAVE OCCURRED IN THE REGION OF AL-HAYMAH, WEST OF SAN'A
HAZARDS	A LARGE LANDSLIDE FROM A MOUNTAIN NEAR BAYT AL-NASH DIVERTED THE COURSE OF THE RIVER & DID MUCH DAMAGE
SOURCE	4
COMMENT	MAY NOT BE A GENUINE SEISMIC EVENT

464.

DATE	AD 1873 Feb 14
EPICENT.	OFF THE COAST OF TYRE, LEBANON
MAG.	ML 6.2
FELT IN	LEBANON, EGYPT, ISRAEL, SYRIA, TURKEY
DETAILS	STRONG AT TYRE. AFFECTED BEIRUT, SUEIDIJE, ANTIOCH & ALEPPO. ALSO AFFECTED JAFFA, JERUSALEM & CAIRO
SOURCE	12,17,19

465.

DATE	AD 1873 Jun 20 and 21
FELT IN	IRAQ
DETAILS	A STRONG SHOCK WAS FELT IN BAGHDAD ON Jun 20. FURTHER SHOCKS WERE FELT ON Jun 21
SOURCE	5

466.

DATE	AD 1873 Jun 29
FELT IN	ISRAEL
DETAILS	SEVERE (?) IN JERUSALEM. (30) GIVES THE THE INTENSITY IN ISRAEL AS =6-7
SOURCE	6,9

467.

DATE	AD 1874
FELT IN	ISRAEL
DETAILS	FELT IN JERUSALEM
SOURCE	19
COMMENT	SAME AS 466?

468.

DATE	AD 1875 Nov 2
EPICENT.	16.0°N 38.5°E
MAG.	ML 6.0
FELT IN	SUDAN, ETHIOPIA
DETAILS	SHOCKS WERE FELT AT SUAKIN. SOME PEOPLE WERE KILLED IN ETHIOPIA. THE EARTHQUAKE AFFECTED THE WEST COAST OF THE RED SEA SOUTH OF PORT SUDAN. THE INTENSITY IN MASSAWA & SUAKIN =5. DAMAGE WAS CAUSED IN SINKAT & GEBEIT WHERE THE INTENSITY =6
SOURCE	12,20,31

469.
DATE AD 1877
FELT IN ISRAEL
DETAILS FELT IN JERUSALEM
SOURCE 19

470.
DATE AD 1878 Summer
FELT IN YEMEN A.R.
DETAILS A LONG SEQUENCE OF TREMORS AFFECTED THE TOWNS OF DHAMAR & YARIM & THEIR RESPECTIVE REGIONS
SOURCE 4

471.
DATE AD 1879
FELT IN ISRAEL
DETAILS AFFECTED JERUSALEM
SOURCE 19

472.
DATE AD 1879 Jul 11
EPICENT. OFF ALEXANDRIA, EGYPT
INTENS. 5
MAG. 4.8
FELT IN EGYPT
DETAILS THE EARTHQUAKE WAS STRONGLY FELT IN EGYPT
SOURCE 21

473.
DATE AD 1880 Nov 10-11
EPICENT. RED SEA (approx 17.5°N 40.0°E)
INTENS. 9
MAG. ML 6.1
FELT IN ETHIOPIA, ARABIA
DETAILS FELT IN MASSAWA (ETHIOPIA) & JIDDAH
SOURCE 12

474.
DATE AD 1884 Mar
EPICENT. PERSIAN GULF
FELT IN OMAN
DETAILS A STRONG EARTHQUAKE AFFECTED MUSKAT & NEDJD
SOURCE 13

475.

DATE	AD 1884 May 19
EPICENT.	PERSIAN GULF
FELT IN	OMAN, IRAN
DETAILS	A STRONG EARTHQUAKE AFFECTED QESHM ISLAND
SOURCE	13,38

476.

DATE	AD 1884 Jul 20
INTENS.	8
FELT IN	EGYPT, ETHIOPIA, RED SEA
DETAILS	A SMALL SHOCK AFFECTED MASSAWA (ETHIOPIA) ON THE RED SEA SHORELINE. LIMITED DAMAGE WAS CAUSED
SOURCE	13,31

477.

DATE	AD 1884 Jul 23
EPICENT.	RED SEA (17.0°N 40.0°E)
INTENS.	11
MAG.	ML 7.4
FELT IN	ETHIOPIA, EGYPT, OMAN
DETAILS	EPICENTRE NORTH OF THE DAHLAK ISLANDS. DESTRUCTION WAS CAUSED IN MASSAWA (ETHIOPIA). THE EARTHQUAKE WAS FELT STRONGLY IN CAIRO AND MUSKAT
HAZARDS	TSUNAMI IN RED SEA
SOURCE	12

478.

DATE	AD 1886 Aug 27
EPICENT.	EAST OF PELOPONNESUS, GREECE (37.0°N 21.25°E)
INTENS.	11
MAG.	ML 8.0-8.4
FELT IN	EGYPT, SYRIA, ASIA MINOR, GREECE, ALBANIA, MALTA
DETAILS	THE EARTHQUAKE AFFECTED THE NILE DELTA. ALSO THE SOUTH COAST OF PELOPONNESUS, MESENIA, PYLOS, PHILIATRA (600 DEAD), TRIPHYLIE AND MARATHOS (326 DEAD), MOREA AND THE ISLAND OF ZANTE (300 DEAD)
HAZARDS	A TSUNAMI IN THE MEDITERRANEAN
SOURCE	12,13,17,31
COMMENT	(38) CITES THE EPICENTRE AS WEST PELOPONNESUS, WHICH SEEMS MORE LIKELY

479.

DATE AD 1887 Jul 17

FELT IN EGYPT, SUDAN

DETAILS A SMALL SHOCK AFFECTING CAIRO & THE NILE VALLEY. SOME HOUSES IN CAIRO WERE DAMAGED. THE EARTHQUAKE ALSO AFFECTED SUAKIN

SOURCE 13,20

480.

DATE AD 1895 Aug 2

FELT IN YEMEN A.R.

DETAILS A SERIES OF SHOCKS AFFECTING MUKHA & TA'IZZ

SOURCE 4

481.

DATE AD 1896 Jun 29

EPICENT. NEAR CYPRUS (34.2^{o}N 33.0^{o}E)

INTENS. 9-10

MAG. ML 6.8

FELT IN SYRIA, LEBANON, ISRAEL, EGYPT, TURKEY

DETAILS INTENSITY IN JERUSALEM =SM 4-5 & AT SAFED =SM 5 THE EARTHQUAKE ALSO AFFECTED HAIFA, TIBERIAS & ET-TABGHA. AT CAIRO THE INTENSITY =3

SOURCE 6,12,17

APPENDIX A2

INDEX TO COUNTRIES LISTED IN THE CATALOGUE

Each record in the historical catalogue has a number. The records referring to particular countries are listed below:-

BAHRAIN

317

EGYPT

3	83	151	191	262	296	328	351	410	461
18	85	152	202	266	298	329	352	420	462
24	110	154	203	267	300	330	358	422	464
29	113	155	217	277	301	332	359	423	472
35	115	156	238	279	302	335	361	435	476
46	116	158	244	280	303	336	362	436	477
55	123	160	245	281	315	337	363	437	478
57	134	168	246	285	316	339	367	439	479
66	136	171	247	287	319	347	383	440	481
68	137	180	251	289	320	348	385	446	
74	145	182	253	291	321	349	392	458	
82	150	190	258	293	326	350	397	460	

IRAN

129	138	178	185	197	245	342	370	378	411
131	147	182	193	217	254	257	371	395	475
134	166	183	194	219	305	360	376	408	481
135	175								

IRAQ

9	107	137	164	190	216	245	282	384	450
18	115	138	165	193	217	246	322	386	451
19	118	139	166	195	218	247	334	389	452
20	127	142	167	197	223	252	342	407	453
82	130	144	174	208	226	254	357	411	455
83	131	149	178	212	238	255	371	419	457
86	132	156	185	213	240	256	376	434	462
89	134	157	186	214	241	265	382	445	465
93	135	162	188	215					

ISRAEL

1	31	68	93	121	184	238	308	378	435
4	33	69	95	124	187	242	323	388	440
5	34	71	98	125	188	246	327	395	443
7	35	72	100	133	189	251	328	400	446
10	36	73	101	134	190	263	331	402	447
12	37	74	104	135	191	269	338	403	448
13	38	77	105	137	200	274	344	418	459
14	39	78	106	143	203	275	353	421	461
15	41	79	108	148	206	278	354	423	462
16	43	81	112	156	207	280	355	424	464
17	48	82	114	173	209	281	356	428	466
18	49	83	115	176	220	286	360	429	467
23	50	86	116	179	225	294	362	430	469
27	54	89	119	180	234	297	374	431	471
28	56	91	120	181	237	299	376	433	481
29	67								

JORDAN

10	16	49	79	116	188	242	251	289	400
12	34	67	105	131	220	245	269	324	428
14	36	77	115	173	237	246	278	355	429
15									

LEBANON

17	37	82	125	188	241	286	395	423	462
21	54	83	131	211	243	308	400	429	464
22	65	86	168	224	245	314	402	438	481
27	76	88	180	236	247	331	406	440	
28	79	89	182	238	263	374	418	441	

LIBYA

24	68	69	83	131	247	280

OMAN

474	475	477

SAUDI ARABIA

83	102	115	137	146	210	247	271	329	413
96	103	135	140	190	244	257	304	369	473
97	113								

SINAI

7	11	283	362	365	379	417	432

SYRIA

2	59	87	120	170	221	247	299	375	415
8	60	89	121	172	224	249	305	387	416
26	61	90	122	177	227	250	307	390	418
27	62	92	128	180	229	259	308	391	423
29	63	93	129	182	230	270	309	393	424
31	64	94	130	188	231	272	310	394	425
32	65	99	131	190	232	273	311	395	426
37	66	100	134	195	233	274	312	396	427
40	70	101	135	196	234	275	313	398	429
42	71	104	137	198	235	276	314	399	435
43	72	109	141	199	236	279	323	400	438
44	74	110	148	203	238	280	327	401	440
48	75	111	153	206	239	284	333	402	441
49	76	114	156	211	241	286	355	404	461
50	78	115	161	215	242	288	360	405	462
51	81	116	163	216	243	289	368	406	464
52	82	117	168	217	245	290	370	409	478
58	86	119	169	220	246	294	374	412	481

TURKEY (ASIA MINOR)

37	61	78	114	196	238	270	323	400	446
39	66	82	135	204	239	274	327	423	450
40	69	86	137	205	245	275	328	424	461
43	72	88	153	224	247	290	390	428	464
49	74	104	156	228	249	314	391	440	478
58	76	110	188						

YEMEN ARAB REPUBLIC (N. YEMEN)

103	135	260	292	306	341	346	377	413	463
113	192	261	295	318	343	372	380	414	470
126	222	264	304	325	345	373	381	442	480
134	248	268							

YEMEN PEOPLES DEMOCRATIC REPUBLIC (S. YEMEN)

126	222	295	304	340	366	442	461

APPENDIX A3

INDEX TO HAZARDS OTHER THAN EARTHQUAKES IN THE CATALOGUE

The records referring to hazards associated with earthquake events are as follows:-

FAULTING

34	118	245	314	376	411	428	429	450	456
115	218	310	355	402					

GROUND FAILURE (Rockfalls, Landslides or Liquefaction)

3	28	133	149	218	263	283	372	384	453
10	82	134	180	219	269	355	381	429	463
18	113	137	217	241					

SEICHE

18	56	67	115	355	400	429	430

TSUNAMI

8	29	65	86	175	279	314	353	404	440
17	35	66	115	179	280	328	355	405	461
21	48	68	125	180	281	331	395	423	477
22	54	74	137	190	290	338	400	429	478
28	64	83	143	246	308				

VOLCANIC ERUPTION

102 257

APPENDIX A4

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APPENDIX B1

THE HISTORICAL CATALOGUE (PART II)

1.

DATE	BC 221
EPICENT	SIWA OASIS, EGYPT
INTENS.	8
FELT IN	EGYPT, LIBYA
DETAILS	AFFECTED SIWA OASIS IN THE WESTERN DESERT OF EGYPT. FELT OVER AN AREA OF 100,000 sq km IN WESTERN EGYPT AND EASTERN LIBYA
SOURCE	19

2.

DATE	AD 262
FELT IN	ASIA MINOR, LIBYA
DETAILS	A LARGE EARTHQUAKE DESTROYED CYRENE
SOURCE	1,16

3.

DATE	AD 365 Jul 21
EPICENT	ALBORAN SEA
MAG.	6.3
FELT IN	MOROCCO
DETAILS	AFFECTED TANGER AND ITS REGION, AND ALONG THE NORTH COAST OF MOROCCO
SOURCE	9

4.

DATE	AD 365 Jul 21
EPICENT	(35.5N 25.5E) - NEAR KNOSSOS, S.W. CRETE
INTENS.	10-11
MAG.	ML 7.7
FELT IN	ISRAEL, EGYPT, LIBYA, SICILY, GREECE
DETAILS	A LARGE EARTHQUAKE DESTROYED CYRENE. SEE PART I OF CATALOGUE FOR DETAILS CONCERNING EASTERN MEDITERRANEAN COUNTRIES
HAZARDS	A TSUNAMI IN THE EASTERN MEDITERRANEAN AFFECTED EGYPT, LIBYA AND SICILY
SOURCE	16,19

5.

DATE	AD 367 Oct 11
EPICENT	NEAR CYPRUS
INTENS.	9-10
MAG.	ML 6.7
FELT IN	ISRAEL, TURKEY, LIBYA, SICILY
DETAILS	THOUSANDS DEAD. A SEVERE EVENT THAT AFFECTED NICEA, TURKEY
SOURCE	19

6.

DATE	AD 382
EPICENT	CAPE SAN VICENTE, PORTUGAL
MAG.	6.75
FELT IN	MOROCCO
DETAILS	AFFECTED TANGER & ITS REGION, AND ALONG THE NORTH COAST OF MOROCCO
SOURCE	9

7.

DATE	AD 408 or 412
EPICENT	NEAR UTICA, TUNISIA
FELT IN	TUNISIA
DETAILS	A SERIES OF DESTRUCTIVE EARTHQUAKES NEAR UTICA. AFTERSHOCKS LASTED FOR 1 WEEK
HAZARDS	FAULT MOVEMENTS NEAR UTICA
SOURCE	7

8.

DATE	AD 551 Jul 9
EPICENT	OFF COAST OF BEIRUT, LEBANON (33.9N 35.5E)
INTENS.	11-12
MAG.	ML 7.8
FELT IN	LEBANON, EGYPT, IRAQ, ARABIA, ISRAEL, GREECE
DETAILS	A SEVERE EVENT THAT AFFECTED THE MAGHREB. SEE PART I OF CATALOGUE FOR DETAILS CONCERNING EASTERN MEDITERRANEAN COUNTRIES
SOURCE	19

9.

DATE	AD 704
FELT IN	LIBYA
DETAILS	STRONG EARTHQUAKE FELT ALONG THE LIBYAN COAST. AFFECTED THE FEZZAN AREA AND DESTROYED MANY TOWNS & VILLAGES
SOURCE	10,16
COMMENT	THIS IS ONE OF ONLY TWO EVENTS WHICH HAVE BEEN LOCATED IN SOUTHERN LIBYA (SEE ALSO 112).

10.

DATE	AD 846 Aug 28
FELT IN	NORTH AFRICA
SOURCE	2

11.

DATE	AD 847 possibly Nov 24
FAULT	BEKA'A?, LEBANON
MAG.	ML 6.2?
FELT IN	LEBANON, SYRIA, LIBYA, ALGERIA, TUNISIA
DETAILS	SEE PART I OF CATALOGUE FOR DETAILS CONCERNING EASTERN MEDITERRANEAN COUNTRIES
SOURCE	19
COMMENT	UNCERTAINTY SURROUNDS THE LOCATION OF THE EPICENTRE OF THIS EVENT

12.

DATE	AD 854 Jun 2 or 855
EPICENT	35.42N 10.01E
FELT IN	TUNISIA
DETAILS	AN EARTHQUAKE IN NORTHERN TUNISIA DESTROYED 13 VILLAGES AROUND KAIROUAN. MODERATE DAMAGE IN KAIROUAN (INTENSITY =10). ALSO AFFECTED TUNIS
HAZARDS	GROUND SLUMPING & SETTLING OBSERVED IN VALLEYS
SOURCE	2,3,7

13.

DATE	AD 856 Dec 3
EPICENT	37.0N 10.0E
FELT IN	TUNISIA
DETAILS	A GREAT EARTHQUAKE IN TUNIS & ITS DEPENDENCIES. EXTREME DAMAGE & 45,000 DEAD AT TUNIS
SOURCE	2,7
COMMENT	A LARGE EARTHQUAKE OCCURRED IN THE EASTERN MEDITERRANEAN AT THIS TIME - SEE PART I OF CATALOGUE FOR DETAILS

14.

DATE	AD 859
FELT IN	NORTH AFRICA
DETAILS	AFFECTED THE MAGHREB
SOURCE	3
COMMENT	A LARGE EARTHQUAKE OCCURRED IN THE EASTERN MEDITERRANEAN DURING THIS YEAR - SEE PART I OF CATALOGUE FOR DETAILS

15.

DATE	AD 881 May 26 or May 27
INTENS.	10
FELT IN	SPAIN, MOROCCO, ALGERIA
DETAILS	FELT IN ANDALUCIA (SOUTHERN SPAIN) AND ALL MOROCCO
HAZARDS	ROCKFALLS OCCURRED IN ASSOCIATION WITH THIS EVENT. A TSUNAMI OCCURRED ALONG THE COAST OF SPAIN IN AD 881 (12), AND MAY BE RELATED TO THIS EVENT
SOURCE	3,9,12,18

16.

DATE	AD 912
EPICENT	35.42N 10.01E?
FELT IN	TUNISIA
DETAILS	INTENSITY AT KAIROUAN =8
SOURCE	3

17.

DATE	AD 978
FELT IN	NORTH AFRICA
DETAILS	AFFECTED THE MAGHREB
SOURCE	3

18.

DATE	AD 981 Nov
EPICENT	39.59N 11.03E approx
FELT IN	TUNISIA
DETAILS	AFFECTED MAHDIA
SOURCE	3

19.

DATE	AD 1040 Feb 2
FELT IN	IRAN, TURKEY, NORTH AFRICA
SOURCE	1

20.

DATE	AD 1079
FELT IN	NORTH AFRICA
DETAILS	AFFECTED THE MAGHREB
SOURCE	3

21.

DATE	AD 1170 Jun 29
EPICENT	EASTERN MEDITERRANEAN
INTENS.	11-12
MAG.	ML 7.9
FELT IN	SYRIA, IRAQ, TURKEY, LEBANON, ISRAEL, EGYPT, NORTH AFRICA, SICILY
DETAILS	AFFECTED THE NORTH COAST OF AFRICA. ALSO FELT IN GERMANY, SWITZERLAND AND HUNGARY. SEE PART I OF CATALOGUE FOR DETAILS CONCERNING EASTERN MEDITERRANEAN COUNTRIES
SOURCE	1,19

22.

DATE	AD 1183
FELT IN	LIBYA
DETAILS	STRONG EARTHQUAKE AFFECTING THE LIBYAN COAST. TRIPOLI WAS BADLY DESTROYED AND ABOUT 20,000 PEOPLE KILLED
SOURCE	10,13,16

23.

DATE	AD 1203
FELT IN	EGYPT, SYRIA, CYPRUS, SICILY, LEBANON, GREECE, ARABIA, IRAQ, TURKEY, NORTH AFRICA
DETAILS	AFFECTED THE MAGHREB. SEE PART I OF CATALOGUE FOR DETAILS CONCERNING EASTERN MEDITERRANEAN COUNTRIES
SOURCE	3,19
COMMENT	POSSIBLY PARTLY CONFUSED WITH 24

24.

DATE	AD 1203 or 1204
FELT IN	MOROCCO
DETAILS	FELT IN TANGER AND ITS REGION, AND ALONG THE NORTH COAST OF MOROCCO. STRONG AT CEUTA
SOURCE	9

25.

DATE	AD 1276
MAG.	6.3
FELT IN	MOROCCO
DETAILS	FELT IN TANGER AND ITS REGION, AND ALONG THE NORTH COAST OF MOROCCO. DESTRUCTIVE AT EL ARAISCH (LARACHE). NUMEROUS DEAD
SOURCE	9,14

26.

DATE	AD 1303 Jul 8 (Aug 8)
EPICENT	OFF ALEXANDRIA, EGYPT
INTENS.	11
MAG.	ML 7.6
FELT IN	LIBYA, TUNISIA, SICILY, SYRIA, ISRAEL, CYPRUS, CRETE, JORDAN, EGYPT
DETAILS	AFFECTED CYRENAICA AND GABES. SEE PART I OF CATALOGUE FOR DETAILS CONCERNING EASTERN MEDITERRANEAN COUNTRIES
HAZARDS	TSUNAMI IN THE EASTERN MEDITERRANEAN
SOURCE	3,19

27.
DATE AD 1504 Apr 5
EPICENT NEAR CARMONA (SEVILLA), SPAIN
FELT IN SPAIN, PORTUGAL, MOROCCO
DETAILS EXTENSIVE DAMAGE AND LOSS OF LIVES IN CARMONA & NEARBY TOWNS. THE EARTHQUAKE WAS FELT IN MEDINA DEL CAMPO (500km FROM CARMONA), THE ALGARVE, THE PROVINCE OF MURCIA & NORTH MOROCCO
SOURCE 17

28.
DATE AD 1522
FELT IN MOROCCO
DETAILS DESTROYED FES AND SURROUNDING VILLAGES
SOURCE 14

29.
DATE AD 1531 Jan 26
EPICENT PROBABLY AT SEA, S.W. OF CAPE SAN VICENTE, PORTUGAL
INTENS. BELIEVED BY SOME AUTHORS TO HAVE BEEN AS GREAT AS THAT OF THE EARTHQUAKE OF 1755
FELT IN SPAIN, PORTUGAL, SWITZERLAND, HOLLAND, MOROCCO
DETAILS 1,500 HOUSES DESTROYED IN LISBON (INTENSITY =10). 30,000 DEAD. AFFECTED THE REMAINDER OF PORTUGAL & SPAIN, NORTH MOROCCO, THE CANTON DU VAUD IN SWITZERLAND, AND FLANDERS
HAZARDS THE SEA WAS GREATLY AGITATED BY THIS EVENT. THERE WERE TSUNAMIS ALONG THE SOUTH WEST COAST OF PORTUGAL
SOURCE 1,2,17

30.
DATE AD 1579
FELT IN MOROCCO
DETAILS PARTIAL DESTRUCTION OF MELILLA
SOURCE 14

31.
DATE AD 1591 Jul 26
FELT IN AZORES
DETAILS AFFECTED ST.MICHAEL
HAZARDS SEA GREATLY AGITATED
SOURCE 12

32.
DATE AD 1614 May 4
FELT IN AZORES
DETAILS AFFECTED THE ISLANDS OF TERCEIRA, ANGRA AND PRAYA
SOURCE 1

33.
DATE AD 1624 May 11
EPICENT 34.05N 5.0W
FELT IN MOROCCO
DETAILS TOTAL DESTRUCTION OF FES (INTENSITY =8-9). GREAT DAMAGE AT MEKNES. ACCORDING TO (14) THERE WAS ALSO GREAT DAMAGE AT PENON DE LA GOMERA, CANARY ISLANDS
SOURCE 3,14

34.
DATE AD 1654 Oct 20
EPICENT 40.1N 3.6E
INTENS. 9
FELT IN MINORCA
DETAILS MANY DEAD. LIMITED DAMAGE IN MINORCA
SOURCE 2

35.
DATE AD 1660
FELT IN MOROCCO
DETAILS DISASTEROUS EARTHQUAKE AT MELILLA
SOURCE 14

36.
DATE AD 1662
FELT IN NORTH AFRICA
DETAILS AFFECTED THE MAGHREB
SOURCE 3

37.
DATE AD 1665 Mar 28
FELT IN MOROCCO
DETAILS VIOLENT EARTHQUAKE AT FES (INTENSITY =8)
SOURCE 3,14

38.
DATE AD 1680 Oct 9
EPICENT ALBORAN SEA, NEAR MALAGA, SPAIN
MAG. 6.75
FELT IN MOROCCO, SPAIN
DETAILS AFFECTED AREA RESTRICTED MAINLY TO SOUTHERN SPAIN & NORTH MOROCCO. IN MALAGA ALONE, MORE THAN 850 HOUSES WERE TOTALLY DESTROYED & 1250 SERIOUSLY DAMAGED. IN GRANADA MOST HOUSES SUFFERED SEVERE DAMAGE. AFFECTED TANGER AND ITS REGION & THE NORTH COAST OF MOROCCO
SOURCE 9,17

39.
DATE AD 1693
FELT IN MOROCCO
DETAILS VIOLENT EARTHQUAKE IN THE BAY OF ALHUCEMAS
SOURCE 14

40.
DATE AD 1715 May or Aug 5?
EPICENT 36.5N 2.6E
FELT IN ALGERIA
DETAILS 20,000 DEAD. UNKNOWN DAMAGE IN ALGER
SOURCE 2,5

41.
DATE AD 1716 Feb 3 at 2H
EPICENT ATLAS MOUNTAINS - EXACT EPICENTRE UNKNOWN
INTENS. 10
FELT IN ALGERIA
DETAILS A HIGHLY DESTRUCTIVE EARTHQUAKE NEAR BLIDA CAUSING 20,000 DEATHS. DESTRUCTIVE IN CENTRAL ALGERIA AT MEDEA. AT ALGER ALL THE HOUSES WERE DAMAGED, MANY COLLAPSED, AND A LARGE NUMBER OF FIRES BROKE OUT. AFTERSHOCKS OCCURRED ON Feb 4, 5 & 26 (THAT OF Feb 26 WAS AS STRONG AS THAT OF Feb 3). THE HOUSES OF ALGER WERE REBUILT TO RESIST FUTURE EARTHQUAKE EVENTS
HAZARDS NEAR TO ALGER THERE WAS A 4km STRETCH OF LAND THAT "TUMBLED DOWN JUST TO A STADE FROM THERE, WHERE ITS DEBRIS FINALLY STOPPED CLOSE TO THE RIVER HARBEENE"
SOURCE 1,2,4,8,10,11,18
COMMENT CONFUSED WITH 42?

42.
DATE AD 1716 May-June
EPICENT ATLAS MOUNTAINS?, ALGERIA
FELT IN ALGERIA, SICILY
DETAILS IN May & June, VIOLENT SHOCKS WERE AGAIN FELT IN ALGER. MORE THAN 20,000 PEOPLE DIED (SEE COMMENT). THIS EARTHQUAKE WAS EQUALLY DESTRUCTIVE AT BLIDA, AND WAS FELT AT CATANIA & SYRACUSE
SOURCE 1,11
COMMENT CONFUSED WITH 41?

43.
DATE AD 1717 Aug 5 at 23H
EPICENT EXACT EPICENTRE UNKNOWN
FELT IN ALGERIA
DETAILS A LARGE EARTHQUAKE CAUSED GREAT DEVASTATION AT ALGER. 20,000 DEAD (MORTALITY FIGURE CONFUSED WITH ABOVE?)
SOURCE 1,2,11,13

44.
DATE AD 1719 Jul
FELT IN MOROCCO
DETAILS DESTRUCTION OF MARRAKECH AND OF VARIOUS VILLAGES. THE EARTHQUAKE AFFECTED THE COASTAL REGION AND WAS FELT AT FES
SOURCE 1,14

45.
DATE AD 1721 Mar 24
FELT IN MAJORCA
DETAILS AFFECTED THE ISLAND OF MAJORCA
SOURCE 1

46.
DATE AD 1722 Nov 29
EPICENT EXACT EPICENTRE UNKNOWN
FELT IN ALGERIA
DETAILS HOUSES WERE DAMAGED IN ALGER BY SEVERAL SHOCKS. THE HOUSES WERE EITHER CRACKED OR DESTROYED
SOURCE 1,11

47.
DATE AD 1724
FELT IN ALGERIA, TUNISIA
DETAILS AN EARTHQUAKE SHOOK PRINCIPALLY IN ALGER. THE EARTHQUAKE EXTENDED FROM MILIANA TO CAPE BON
SOURCE 7

48.
DATE AD 1731
FELT IN MOROCCO
DETAILS TOTAL DESTRUCTION OF AGADIR (FORMERLY CALLED SANTA-CRUZ)
SOURCE 4,14

49.
DATE AD 1750 Oct 5
FELT IN TUNISIA
DETAILS A STRONG EARTHQUAKE SHOOK NORTH AFRICA FROM SFAX TO CAPE BON
SOURCE 7

50.
DATE AD 1755
FELT IN AZORES
DETAILS UNCERTAINTY CONCERNING WHETHER THIS WAS A SEISMIC OR VOLCANIC EVENT
SOURCE 1

51.
DATE AD 1755 Nov 1
EPICENT 36.0N 11.0W - S.W. OF CAPE SAN VICENTE, PORTUGAL
MAG. 8.75
FELT IN PORTUGAL, SPAIN, MOROCCO
DETAILS 55,000-62,000 DEAD AT LISBON & EXTREME DAMAGE (INTENSITY =11). WIDESPREAD DAMAGE IN N.W. MOROCCO WITH 10,000 DEAD. INTENSITY AT FES =10-11. IN MOROCCO THERE WERE THOUSANDS OF VICTIMS, AND ENORMOUS DAMAGE AT MARRAKECH, MEKNES, CEUTA, TANGER, CASABLANCA, SAFI & AGADIR. ALSO CAUSED EXTENSIVE DAMAGE IN MANY TOWNS & CITIES OF PORTUGAL & SPAIN
HAZARDS TSUNAMI WAVES 15'-40' HIGH ALONG PORTUGUESE

(cont.)

& SPANISH COASTS, 15' HIGH AT MADEIRA. VERY HIGH AT CADIZ WHERE 18 WAVES ROLLED IN. MAXIMUM WAVE HEIGHT = 21' IN THE WEST INDIES. ROCKFALLS ON THE MOROCCAN COAST

SOURCE 2,3,4,5,9,12,17,18

52.

DATE AD 1755 Nov 2

MAG. 6.75

FELT IN MOROCCO

DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO

HAZARDS TSUNAMI AT GIBRALTAR

SOURCE 9

53.

DATE AD 1755 Nov 3

MAG. 4.5

FELT IN MOROCCO

DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. FELT AT GIBRALTAR & CEUTA

SOURCE 9

54.

DATE AD 1755 Nov 4

FELT IN MOROCCO

DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. FELT AT GIBRALTAR & CEUTA

SOURCE 9

55.

DATE AD 1755 Nov 5

MAG. 4.25

FELT IN MOROCCO

DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO

SOURCE 9

56.

DATE AD 1755 Nov 6-16

FELT IN MOROCCO

DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. DAILY SHOCKS AT CEUTA

SOURCE 9

57.
DATE AD 1755 Nov 17
MAG. 5 approx
FELT IN MOROCCO
DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. FELT AT CEUTA & GIBRALTAR
SOURCE 9

58.
DATE AD 1755 Nov 18
FELT IN MOROCCO
DETAILS A VIOLENT EARTHQUAKE. AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. FELT AT TETOUAN, WITH DESTRUCTION AT FES & MEKNES ON THE 18th & 19th Nov. 3,000 DEAD AT FES
SOURCE 9,14

59.
DATE AD 1755 Nov 19
EPICENT 34.1N 5.3W
FELT IN MOROCCO, FRANCE, GERMANY
DETAILS SEVERE DAMAGE AT MEKNES. SLIGHT SHOCKS WERE FELT ALONG THE RHINE, IN THE BREISGAU, AND AT AIX IN SAVOY
HAZARDS POSSIBLE LANDSLIDING/FAULTING AT ZERHOUN THAT MAY BE ASSOCIATED WITH THIS EVENT. ALSO POSSIBLE LIQUEFACTION NEAR MEKNES
SOURCE 1,2,18

60.
DATE AD 1755 Nov 20
FELT IN MOROCCO
DETAILS 3 STRONG SHOCKS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. FELT AT TETOUAN
SOURCE 9

61.
DATE AD 1755 Nov 28
FELT IN MOROCCO
DETAILS AFFECTED FES AND MEKNES. INTENSITY AT MEKNES =10
SOURCE 3

62.
DATE AD 1757
FELT IN TUNISIA
DETAILS MAJOR EARTHQUAKE IN WESTERN TUNISIA. 3,000 DEAD
SOURCE 4

63.
DATE AD 1757 Apr 15 or May 15
EPICENT OFFSHORE
FELT IN MOROCCO
DETAILS WIDESPREAD DAMAGE IN WESTERN MOROCCO FROM AN OFFSHORE EARTHQUAKE. 3,000 DEAD. PARTICULARLY AFFECTED SALE ON THE COAST & CAP CANTIN; AT BOTH PLACES, NUMEROUS BUILDINGS WERE DESTROYED
SOURCE 1,4,14

64.
DATE AD 1757 Jul 9
FELT IN AZORES
DETAILS FELT THROUGHOUT THE AZORES AT ANGRA (TERCEIRA) & THE ISLAND OF ST.GEORGE
HAZARDS TSUNAMI AFFECTED ST.GEORGE ISLAND, THE PIC & GRACIOSA
SOURCE 1,12

65.
DATE AD 1757 Jul 10
FELT IN AZORES
DETAILS FELT THROUGHOUT THE AZORES. AFFECTED NORTE GRANDE, ISLAND OF ST.GEORGE & ISLAND OF TOPO
SOURCE 1

66.
DATE AD 1758 Jan
EPICENT PROBABLY NEAR CONSTANTINE, ALGERIA
FELT IN ALGERIA, TUNISIA
DETAILS THE PROVINCE OF CONSTANTINE WAS DEVASTATED BY NUMEROUS EARTHQUAKES. AFFECTED SEVERAL PLACES IN TUNISIA, WITH TUNIS EXPERIENCING VIOLENT SHOCKS. A LARGE NUMBER OF HOUSES COLLAPSED & SEVERAL THOUSAND PEOPLE WERE KILLED. SOME SUGGESTION OF 2 EVENTS
SOURCE 1,5,7,11
COMMENT POSSIBLY 2 EVENTS

67.
DATE AD 1761 Mar 31
EPICENT PROBABLY UNDER THE ATLANTIC
FELT IN SPAIN, PORTUGAL, FRANCE, HOLLAND, IRELAND, AZORES, BARBARY
DETAILS AFFECTED LISBON (NO DEAD & INSIGNIFICANT DAMAGE), OPORTO, MADRID, SANTA CRUZ, BORDEAUX, AMSTERDAM, CORK AND FUNCHAL (MADEIRA). DESTRUCTIVE IN THE AZORES & CANARY ISLANDS
HAZARDS TSUNAMI IN THE MEDITERRANEAN & ATLANTIC - AT LISBON THE SEA ROSE 8' AND FLOWED IN & OUT. A 6' TIDAL WAVE OCCURRED AT CORNWALL, AND A LARGE WAVE WAS NOTED AT MADEIRA, AZORES AND BARBADOS
SOURCE 1,2,12,17
COMMENT THIS WAS THE FIRST IN A SEQUENCE OF LARGE SHOCKS. A TOTAL OF 14 WERE FELT IN THE INTERVAL BETWEEN Mar 31 AND Jun 14, 1761

68.
DATE AD 1761 Apr 9
FELT IN NORTH AFRICA, BARBARY
DETAILS AFFECTED SANTA CRUZ
SOURCE 1

69.
DATE AD 1764 Oct 12
FELT IN AZORES
DETAILS AFFECTED FAIAL
SOURCE 1

70.
DATE AD 1773 Jan
FELT IN MOROCCO
DETAILS AFFECTED OLD FEZ WHICH WAS BADLY DAMAGED. TANGER WAS TOTALLY DESTROYED & THERE WAS IMPORTANT DAMAGE AT SALE
SOURCE 1,14

71.
DATE AD 1773 Apr 12
MAG. 6.75
FELT IN SPAIN, PORTUGAL, MOROCCO
DETAILS AFFECTED CADIZ, ROTA, SANTA MARIA, PORT ROYAL, LISBON, MADRID, MALAGA & GIBRALTAR. ALSO AFFECTED SALE, TANGER & THE NORTHERN COAST OF MOROCCO. DESTRUCTION AT TANGER
SOURCE 1,9

72.
DATE AD 1773 May 6
FELT IN ALGERIA, MOROCCO
DETAILS NO ACTUAL EARTHQUAKE DAMAGE DESCRIBED
HAZARDS A SERIES OF TSUNAMIS AFFECTED THE NORTH COAST OF AFRICA, PARTICULARLY ALGER & TANGER. THE WAVES WERE 6' HIGH AT MOST PLACES, 30' HIGH AT TANGER
SOURCE 12

73.
DATE AD 1776 Jun 6
FELT IN MOROCCO
DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. FELT AT GIBRALTAR
SOURCE 9

74.
DATE AD 1777
FELT IN MOROCCO
DETAILS ALMOST COMPLETE DESTRUCTION OF TANGER. SALE WAS BADLY AFFECTED & MANY PEOPLE SUFFERED
SOURCE 14

75.
DATE AD 1785 Nov 9
MAG. 5
FELT IN MOROCCO
DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. STRONGLY FELT
SOURCE 9

76.

DATE	AD 1787
FELT IN	AZORES
HAZARDS	TSUNAMI IN THE AZORES - THE SEA INUNDATED THE SHORES OF THE ISLANDS
SOURCE	12

77.

DATE	AD 1790 Oct 8
FELT IN	SPAIN, MALTA, ALGERIA
DETAILS	FELT ACROSS THE SOUTHERN COAST OF SPAIN & IN NORTH AFRICA. AFFECTED ORAN, CARTAGENA, MALAGA & SANTA FE
SOURCE	1

78.

DATE	AD 1790 Oct 9 at 1H
EPICENT	35.7N 0.7W - CLOSE TO ORAN, ALGERIA
FAULT	PROBABLY SUBMARINE
INTENS.	10
FELT IN	ALGERIA
DETAILS	HIGHLY DESTRUCTIVE AT ORAN, WHERE 3,000 PEOPLE DIED AND NEARLY ALL THE HOUSES WERE KNOCKED DOWN. FIRES BROKE OUT & THE TOWN WAS EVACUATED. THE ZONE WHERE THE SHOCKS HAD MOST DISASTEROUS EFFECT WAS CONFINED TO THE DEPRESSION BETWEEN THE HIGH GROUND. FELT ON THE COASTS OF MALTA & SPAIN
HAZARDS	GROUND MOVEMENTS OCCURRED AT ORAN. PROCESSES OF LIQUEFACTION LED TO LANDSLIDING
SOURCE	4,8,10,11,18

79.

DATE	AD 1791 and 1792
FELT IN	MOROCCO
DETAILS	MANY EARTHQUAKES AFFECTED MELILLA. THEY OCCURRED ALMOST WITHOUT INTERRUPTION FROM Oct 8, 1791 TO Sep 2, 1792. THE MOST VIOLENT WAS ON Aug 31, 1792. IT DESTROYED NUMEROUS PUBLIC BUILDINGS & A LARGE NUMBER OF THE HOUSES
SOURCE	14

80.

DATE	AD 1800 to 1802
FELT IN	CANARY ISLANDS
DETAILS	FROM Sep 5, 1800 TO Feb 23, 1802, 53 EARTHQUAKES DESTROYED A LARGE PART OF THE FORTIFICATIONS OF PENON DE LA GOMERA
SOURCE	14

81.

DATE	AD 1801 Oct 8
FELT IN	MOROCCO
DETAILS	AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. FELT AT CEUTA
SOURCE	9

82.

DATE	AD 1802 Nov 7 at 11H.45M
EPICENT	UNCERTAIN - POSSIBLY 36.5N 2.9E
FAULT	REGION OF BLIDA?
INTENS.	7-8 or 10?
FELT IN	ALGERIA
DETAILS	VIOLENT SHOCK AT ALGER & BLIDA AND THE AREA AROUND. THE SHOCK WAS PARTICULARLY STRONG AT BLIDA. A VILLAGE OF 200 WAS ENGULFED BY FIRE. THE EARTHQUAKE WAS FELT ON SHIPS OVER 50 MILES FROM THE COAST
SOURCE	1,6,11,15

83.

DATE	AD 1803
FELT IN	LIBYA
DETAILS	A SMALL SHOCK IN TRIPOLI
SOURCE	16

84.

DATE	AD 1807 Nov 18
EPICENT	EXACT EPICENTRE UNKNOWN - POSSIBLY 36.7N 3.0E
INTENS.	8-10?
FELT IN	ALGERIA
DETAILS	VIOLENT SHOCKS AT ALGER CAUSED BUILDINGS TO COLLAPSE. THE SHOCKS LASTED UNTIL Nov 26, 1807
SOURCE	1,6,11,15

85.

DATE	AD 1810 Feb 16
EPICENT	SEA OF CRETE (35.5N 25.0E)
INTENS.	11-12
MAG.	ML 7.8
FELT IN	CRETE, MALTA, ITALY, CYPRUS, ISRAEL, NORTH AFRICA
DETAILS	THE TOWN OF IRAKLION WAS BADLY AFFECTED. ONE-THIRD OF THE HOUSES COLLAPSED KILLING 2,000 PEOPLE (ALSO CITED AS 200 VICTIMS). THE EARTHQUAKE SHOOK A LARGE AREA, AND WAS FELT STRONGLY IN MALTA, NAPLES & NORTH AFRICA. INTENSITY ON CYPRUS =5
SOURCE	6,19

86.

DATE	AD 1810 Mar 20
EPICENT	28.2N 16.6W
FAULT	VOLCANIC?
INTENS.	9
FELT IN	CANARY ISLANDS
DETAILS	A VERY VIOLENT EARTHQUAKE AFFECTED THE ISLAND OF TENERIFFE. MANY PEOPLE PERISHED BENEATH THE RUINS OF THE HOUSES
HAZARDS	THIS EARTHQUAKE WAS POSSIBLY OF VOLCANIC ORIGIN
SOURCE	2,5,6,15
COMMENT	(6) CITES Mar 20 or 25

87.

DATE	AD 1810 Aug 11
FELT IN	AZORES
DETAILS	AFFECTED ST.MIGUEL & LAS CASAS. SHOCKS OCCURRED UNTIL Jan, 1811
SOURCE	1

88.

DATE	AD 1811
EPICENT.	NEAR SIWA OASIS, EGYPT (29.1N 25.9E)
MAG.	5.5
INTENS.	7
FELT IN	LIBYA, EGYPT
DETAILS	STRONG EARTHQUAKE AFFECTING THE LIBYAN COAST. A MAXIMUM INTENSITY OF 7 WAS OBSERVED IN SIWA, WHERE THE TEMPLE OF AMMON WAS DESTROYED. THE EARTHQUAKE WAS FELT OVER A LIMITED AREA IN THE WESTERN DESERT OF EGYPT
SOURCE	10,17,19

89.

DATE	AD 1819 Mar
EPICENT	35.4N 0.1E - CLOSE TO MASCARA, ALGERIA
INTENS.	9-10
FELT IN	ALGERIA, MOROCCO
DETAILS	DISASTEROUS SHOCK IN ALGERIA - ALMOST ALL THE HOUSES AT MASCARA WERE DESTROYED & A LARGE NUMBER OF INHABITANTS PERISHED (INTENSITY =10). AT ORAN THERE WAS ONLY CRACKING OF SOME BUILDINGS
SOURCE	1,6,8,11,15

90.

DATE	AD 1821
FELT IN	MOROCCO
DETAILS	AN EARTHQUAKE THAT WAS VIOLENT ENOUGH TO DESTROY SEVERAL HOUSES & DAMAGE THE FORTIFICATIONS AT MELILLA
SOURCE	14

91.

DATE	AD 1825 Mar 2 at 7H
EPICENT	36.4N 2.8E - ATLAS MOUNTAINS, ALGERIA
INTENS.	10-11
FELT IN	ALGERIA, MOROCCO?
DETAILS	AFFECTED ALGER, BLIDA, CENTRAL ALGERIA & THE COUNTRY LYING TOWARDS THE CANARY ISLS. BLIDA WAS COMPLETELY DESTROYED (7,000 PEOPLE, OR HALF THE POPULATION OF THE TOWN WERE KILLED), AS WERE 2 VILLAGES NEAR-BY. THE WELLS & SPRINGS OF BLIDA DRIED UP SEVERAL HOURS BEFORE THE EARTHQUAKE. 11 VERY VIOLENT AFTERSHOCKS OCCURRED UNTIL Mar 6
HAZARDS	A VILLAGE NEAR BLIDA WAS BURIED BETWEEN 2 HILLS (LANDSLIDE?)
SOURCE	1,2,4,5,6,8,10,11,13,15

92.

DATE	AD 1834 Apr 13
MAG.	4.25
FELT IN	MOROCCO
DETAILS	AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. FELT AT CEUTA
SOURCE	9

93.
DATE AD 1838 Jan 15
MAG. 4.25
FELT IN MOROCCO
DETAILS AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO
SOURCE 9

94.
DATE AD 1839 Apr 14 at 14H.05M
EPICENT UNCERTAIN - POSSIBLY IN THE BIBANS OR BABORS, ALGERIA
FELT IN ALGERIA
DETAILS SHOCK STRONGLY FELT AT CONSTANTINE & ALGER, WHERE SOME DELAPIDATED HOUSES COLLAPSED.
SOURCE 6,11

95.
DATE AD 1841 Jun 14 or 15
FELT IN AZORES
DETAILS AFFECTED THE ISLAND OF TERCEIRA
SOURCE 1

96.
DATE AD 1841 Aug 6
FELT IN MOROCCO
DETAILS AFFECTED THE NORTH COAST OF MOROCCO. STRONGLY FELT IN TANGER & ITS REGION
SOURCE 9

97.
DATE AD 1842 Dec 4
EPICENT 36.7N 3.0E
INTENS. 7
FELT IN ALGERIA
DETAILS SOME HOUSES DAMAGED AT ALGER
SOURCE 6,15

98.
DATE AD 1846 Nov 1
FELT IN ALGERIA
DETAILS AFFECTED ALGER & CHERCHELL
SOURCE 1

99.
DATE AD 1846 Nov-Dec
EPICENT 36.6N 2.2E - NEAR TO CHERCHELL, ALGERIA
FELT IN ALGERIA
DETAILS FROM Nov 3 TO Dec 8 CHERCHELL WAS SHAKEN BY A SWARM OF SHOCKS. SOME WERE ALSO FELT AT ALGER. THE WALLS OF THE BARRACKS & NEARLY ALL THE HOUSES AT CHERCHELL WERE CRACKED. THERE WERE 23 SHOCKS DURING ONE PARTICULAR DAY
SOURCE 11

100.
DATE AD 1846 Nov 21
FELT IN ALGERIA
DETAILS AFFECTED ALGER & CHERCHELL
SOURCE 1
COMMENT SEE 99

101.
DATE AD 1847 Jun 18 at 5H.40M
EPICENT 36.7N 2.9E
FELT IN ALGERIA
DETAILS HOUSES CRACKED AT DOUERA (INTENSITY =6-7). PLASTER-WORK FELL AT KOUBA & KOLEA (INTENSITY =6-7). BELLS WERE CAUSED TO RING AT CHERCHELL (INTENSITY =6). FELT AT ALGER, BLIDA & ACROSS ALL THE AREAS BORDERING ALGER PROVINCE
SOURCE 1,11

102.
DATE AD 1848 Feb 11
EPICENT 35.2N 3.0W
INTENS. 8
FELT IN MOROCCO
DETAILS A VERY DESTRUCTIVE EARTHQUAKE FELT IN MOROCCO. GREAT DAMAGE AT MELILLA. DURING Mar & Apr NUMEROUS SHOCKS WERE FELT AT MELILLA WHERE THEY CAUSED SOME DAMAGE.
SOURCE 1,6,14,15

103.
DATE AD 1848 Apr 29
FELT IN MOROCCO
DETAILS AFFECTED MELILLA
SOURCE 1
COMMENT SEE 102

104.
DATE AD 1848 Dec 31
FELT IN AZORES
SOURCE 1

105.
DATE AD 1849 Jun 12
FELT IN AZORES
DETAILS AFFECTED PRAYA DE VICTORIA
SOURCE 1

106.
DATE AD 1850 Feb 9
EPICENT 36.3N 4.8E - NEAR ZEMMORA EL GUENZET, BIBAN, ALGERIA
INTENS. 8-9
FELT IN ALGERIA
DETAILS HOUSES DESTROYED IN ZEMMORA EL GUENZET (IN THE BIBANS MASSIF) - INTENSITY =8-9. SOME DAMAGE AT BORDJ-BOU-ARRERIDJ. THE SHOCK WAS FELT AS FAR AWAY AS ALGER & DOUERA, 170km FROM THE EPICENTRE
SOURCE 1,6,8,10,11,15

107.
DATE AD 1850 Apr
FELT IN ALGERIA
DETAILS SOME HOUSES WERE DESTROYED AT BORDJ-BOU-ARRERIDJ
SOURCE NEWSPAPER REPORT

108.
DATE AD 1850 Dec 17 at 12H.30M
EPICENT 36.5N 7.4E
FELT IN ALGERIA, TUNISIA
DETAILS WALLS CRACKED AT GUELMA & ALSO IN THE GORGE THAT RUNS BETWEEN HAMMA AND BERDA. THE SHOCK WAS ALSO FELT STRONGLY IN THE VILLAGES OF MILLESIMO & PETIT HELIOPOLIS. QUITE STRONG AT BONE (ANNABA)
SOURCE 1,11,15

109.
DATE AD 1851 Nov 22 at 9H.30M
EPICENT 35.4N 0.1E - CLOSE TO MASCARA, ALGERIA
INTENS. 8-9
FELT IN ALGERIA
DETAILS A SEVERE SHOCK IN THE PROVINCE OF MASCARA & ORAN. THE MOTION WAS VIOLENT AT MASCARA WHERE THERE WERE 3 SUCCESSIVE SHOCKS. ALL THE FRENCH HOUSES IN MASCARA WERE MORE OR LESS DAMAGED & 3 COLLAPSED. NO DEATHS
SOURCE 6,8,11,15

110.
DATE AD 1851 Dec 4
EPICENT UNKNOWN
FELT IN ALGERIA
DETAILS STRONG SHOCK AT TENIET-EL-HAD
SOURCE 11

111.
DATE AD 1852 Apr 16
FELT IN AZORES
DETAILS AFFECTED ST.MICHAEL
SOURCE 1

112.
DATE AD 1853 Aug 5
FELT IN LIBYA
DETAILS RELATIVELY LARGE EARTHQUAKE IN THE FEZZAN. UNKNOWN NUMBER OF DEAD
SOURCE 4

113.
DATE AD 1854 May 15
EPICENT 36.4N 2.7E - JUST TO THE SOUTH-WEST OF BLIDA, ALGERIA
FELT IN ALGERIA
DETAILS DAMAGE TO SEVERAL HOUSES AT BLIDA
HAZARDS LANDSLIDES IN THE VALLEYS OF LA CHIFFA
SOURCE 1,11

114.

DATE AD 1855 Feb 5

FELT IN ALGERIA

DETAILS VIOLENT SHOCK AFFECTED OUENNOUPHA & MELOUZA. HOUSES COLLAPSED AT MELOUZA AFTER THE SHOCK. FELT ACROSS THE PLAIN & IN THE MOUNTAINS. SOME DOUBT EXPRESSED CONCERNING THIS EVENT, AND THE DAMAGE MAY BE ATTRIBUTABLE TO A STORM

HAZARDS LARGE CRACKS IN THE GROUND AT MELOUZA (LIQUEFACTION?)

SOURCE 1,6

COMMENT QUESTIONABLE EVENT

115.

DATE AD 1856 Aug 21 and 22 - 1st SHOCK AT 22H, 2nd SHOCK AT 11H.50M

EPICENT 37.1N 5.7E - SEVERAL km NORTH OF JIJEL, ALGERIA

FAULT SUBMARINE

INTENS. 9-10

FELT IN ALGERIA, FRANCE, MINORCA, SARDINIA, ITALY

DETAILS DESTRUCTIVE ALONG THE ALGERIAN COAST FROM DJIDJELLI (JIJEL) TO BONE (ANNABA). JIJEL (5 DEAD) & COLLO (75 HOUSES IN RUINS) DEVASTATED. BOUGIE (BEJAIA) BADLY AFFECTED. CONSIDERABLE DAMAGE IN PHILIPPEVILLE (SKIKDA) WHICH WAS EVACUATED, SETIF, BATNA, ANNABA, CONSTANTINE, GUELMA, LA CALLE (AL KALA), NICE, MAHON, CARLOFORTE, IGLESIAS & SAN PIETRO. CENTRES OF POPULATION IN THE VALLEY OF SAF-SAF WERE BADLY DAMAGED, ESPECIALLY GASTONVILLE & ROBERTVILLE. OF THE 2 SHOCKS, THAT OF Aug 22 WAS BY FAR THE MOST VIOLENT. NUMEROUS AFTERSHOCKS WERE FELT UNTIL Oct ESPECIALLY AT JIJEL.

HAZARDS TSUNAMI & GROUND FAILURE IN ALGERIA: TSUNAMI ALONG THE COAST (2.3m HIGH). AT BEJAIA THE SEA WITHDREW 35m BEFORE WASHING ASHORE AGAIN 3 TIMES. THE TSUNAMI ALSO AFFECTED MAHON ON MINORCA. FISSURES IN THE GROUND NEAR SKIKDA, AND WATER COLUMNS & ERUPTIONS OF SULPHUROUS MUD AROUND JIJEL. SPRINGS & WELLS DRIED UP PRIOR TO THE EARTHQUAKE e.g. IN L'OUED SAHEL. JEBEL HADDID & BETTACHA IN BENI ZIDDIN AND BENI MERMI WERE SEVERELY SHAKEN CAUSING ROCKFALLS INTO THE VALLEYS. LIQUEFACTION OCCURRED IN THE PLAIN OF L'OUED MERKA - ACROSS THE PLAIN BELOW JEBEL

(cont.)

HALIA, LARGE FISSURES FORMED IN THE SOIL FROM WHICH SHOT OUT A CONSIDERABLE QUANTITY OF WATER (TO A HEIGHT OF SEVERAL METRES) CARRYING SAND & MUD. THESE EMISSIONS ONLY LASTED SEVERAL MINUTES.

SOURCE 1,2,4,6,8,10,11,15,18

COMMENT ACCORDING TO (15) THE 1st SHOCK WAS AT 21H.

116.

DATE AD 1856 Sep 2

FELT IN ALGERIA

DETAILS AFFECTED JIJEL

SOURCE 1

117.

DATE AD 1856 Oct 2

FELT IN ALGERIA

DETAILS AFFECTED SKIKDA

SOURCE 1

118.

DATE AD 1858 Mar 9 at 4H.30M

EPICENT UNCERTAIN

FELT IN ALGERIA

DETAILS 3 SHOCKS WERE FELT SIMULTANEOUSLY AT BLIDA, MILIANA, BOUFARIK, ALGER & CHERCHELL. AT CHERCHELL SEVERAL HOUSES WERE CRACKED. THESE SHOCKS WERE FOLLOWED ON May 10 BY TWO OTHER SHOCKS FELT IN THE SAHEL D'ALGER

SOURCE 1,11

119.

DATE AD 1858 Oct 3

FELT IN ALGERIA

DETAILS AFFECTED AUMALE

SOURCE 1

120.

DATE AD 1860 Sep 27
EPICENT 36.3N 4.5E?
INTENS. 7-8
FELT IN ALGERIA
DETAILS A LIGHT SHOCK AT BORDJ-BOU-ARRERIDJ. STRONGER AT TASMALT. SOME HOUSES COLLAPSED IN THE VILLAGES OF L'OUED-SAHEL UP TO TENSAOUT & TAOURIRT
SOURCE 1,6,11,15

121.

DATE AD 1861 Mar 29
FELT IN ALGERIA
DETAILS AFFECTED BLIDA
SOURCE 1

122.

DATE AD 1861 Apr 27
FELT IN ALGERIA
DETAILS AFFECTED CONSTANTINE & BISKRA
SOURCE 1

123.

DATE AD 1861 Jul 26
FELT IN ALGERIA
DETAILS A VIOLENT SHOCK AT ORAN. THE CHURCH OF ST.LOUIS WAS DAMAGED (CRACKED) AND THERE WAS GENERAL PANIC
SOURCE 6

124.

DATE AD 1862 Jun 8 at 12H.45M
EPICENT 35.7N 0.5E - NEAR TO RELIZANE, ALGERIA
FELT IN ALGERIA
DETAILS VERY STRONG SHOCK AT RELIZANE, PRECEEDED BY A MUFFLED NOISE. MANY HOUSES WERE MORE OR LESS CRACKED. THE SHOCK WAS EQUALLY FELT AT MOSTAGANEM. SEVERAL AFTERSHOCKS WERE FELT AT RELIZANE ON THE SAME DAY
SOURCE 1,11,15

125.
DATE AD 1862 Nov 26
FELT IN ALGERIA
DETAILS AFFECTED TAKITOUNT
SOURCE 1

126.
DATE AD 1862 Nov 30 at OH.25M
EPICENT 36.5N 5.3E - IN THE BABORS NEAR KERRATA, ALGERIA
FELT IN ALGERIA
DETAILS AT TAKITOUNT CHIMNEYS & WALLS WERE CRACKED. THE SHOCK WAS STRONGLY FELT AT SETIF (CLOCKS STOPPED), AND FELT AT BEJAIA, JIJEL & SKIKDA. IT WAS NOT FELT AT CONSTANTINE NOR BORDJ-BOU-ARRERIDJ.
SOURCE 11,15

127.
DATE AD 1863 Sep 7
FELT IN ALGERIA
DETAILS AFFECTED AUMALE
SOURCE 1

128.
DATE AD 1863 Sep 18
FELT IN TUNISIA
DETAILS A SERIES OF EARTHQUAKES IN TUNISIA
SOURCE 7

129.
DATE AD 1864
FELT IN TUNISIA
DETAILS DURING THIS YEAR TUNIS WAS SHAKEN 4 TIMES BY VIOLENT EARTHQUAKES
SOURCE 7

130.
DATE AD 1865 Feb 25
FELT IN ALGERIA
DETAILS SOME WALLS WERE CRACKED BY A SHOCK AT BEJAIA
SOURCE 6

131.

DATE	AD 1867 Jan 2 at 7H.13M. A SECOND MAJOR SHOCK OCCURED AT 9H.40M. NUMEROUS AFTERSHOCKS WERE ASSOCIATED WITH THE EVENT - AT BLIDA ABOUT 20 OCCURRED UP TO Jan 9
EPICENT	36.4N 2.7E or 36.25N 2.41E - 5km SOUTH OF MOUZAIAVILLE, ALGERIA
INTENS.	9-11
FELT IN	ALGERIA
DETAILS	MAIN SHOCK WAS WIDELY FELT. THE VILLAGE OF MOUZAIAVILLE WAS ALMOST COMPLETELY DESTROYED (48 DEAD, 100 INJURED). BOU ROUMI, LA CHIFFA (70 DEAD), EL AFFROUN (18 DEAD, 60 INJURED) WERE ALL SERIOUSLY DAMAGED. STRONG AT AMEUR EL AIN (3 DEAD, SEVERAL INJURED), CHANCELADE & BLIDA (MANY HOUSES CRACKED, PUBLIC BUILDINGS SERIOUSLY DAMAGED). AFFECTED MEDEA (SOME DAMAGE), MARENGO, AIN DEFLA & TIPASA (SLIGHT DAMAGE DESPITE PROXIMITY TO EPICENTRE). HOUSES DAMAGED AT DALMATIE, DOUERE & CHERCHELL. FELT AT MILIANA (LIGHT DAMAGE), BOGHAR, TENIET EL HAD, AUMALE, DELLYS, TIZI OUZOU, DRA EL MIZAN, FORT NATIONAL, ORLEANSVILLE (ECH CHELIFF). VERY WEAK AT JIJEL. THE MAJORITY OF COLLAPSED HOUSES WERE BUILT OF ROCK BOULDERS POORLY CEMENTED TOGETHER. BRICK BUILDINGS SUFFERED VERY LITTLE. LIGHT DAMAGE AT ALGER. NOT FELT AT LAGHOUAT & DJELFA TO THE SOUTH.
HAZARDS	ROCKS FRACTURED BY THE EARTHQUAKE ROLLED INTO THE BOTTOM OF VALLEYS DESTROYING EVERYTHING IN THEIR PATH. FAULTING IN THE MOUNTAINS OF BNI-SALAH. IN PARTICULAR, A FISSURE WAS PRODUCED NEXT TO L'OUADJER WHICH "SPIT FIRE, VAPOURS & TORRENTS OF SULPHUROUS WATER". AFTER Jan 8 SPRINGS DRIED UP IN THE FOOT HILLS OF THE PETIT ATLAS
SOURCE	1,2,4,5,6,8,10,11,15,18
COMMENT	AGAIN, THIS EARTHQUAKE DEMONSTRATES GREATER EAST-WEST PROPAGATION OF SHOCK WAVES THAN NORTH-SOUTH

132.

DATE	AD 1867 Feb 4 at 3H.37M
EPICENT	35.0N 4.0E approx
FELT IN	ALGERIA
DETAILS	STRONG AT DJELFA & BOU-SAADA. LIGHT CRACKING AT FORT NATIONAL. FELT AT BORDJ-BOU-ARRERIDJ, BOGHAR, BISKRA, ALGER, BLIDA, EL-AFFROUN, BOUFARIK & BATNA. NO DAMAGE CAUSED, BUT THE MACROSEISMAL AREA OF THIS EVENT WAS GREATER THAN THAT OF THE EVENT OF Jan 2, 1867 (RADIUS >200km)
SOURCE	11

133.

DATE	AD 1867 Jun 29
FELT IN	ALGERIA
DETAILS	3 STRONG SHOCKS AT MOUZAIAVILLE, PRECEEDED BY A LOUD NOISE. FELT EQUALLY AT BLIDA & AUMALE WHERE PART OF THE POLICE BARRACKS COLLAPSED
SOURCE	11

134.

DATE	AD 1867 Jul 19 at 16H.20M
EPICENT	UNCERTAIN
FELT IN	ALGERIA
DETAILS	VERY STRONG SHOCKS AT SETIF & IN THE SURROUNDING AREA. THE MILL OF L'OUED KERMA EXPERIENCED SOME DAMAGE, AND SEVERAL HOUSES WERE BADLY SHAKEN IN THE VILLAGE OF AL EULMA
SOURCE	11

135.

DATE	AD 1868 Aug 8
FELT IN	MOROCCO
DETAILS	AFFECTED TANGER & ITS REGION, AND THE NORTH COAST OF MOROCCO. 2 SHOCKS WERE FELT AT GIBRALTAR
SOURCE	9

136.

DATE	AD 1868 Aug 17 and 18 - THE FIRST SHOCK WAS AT 17H
EPICENT	36.4N 1.2E approx - MASSIF DU DAHRA?, ALGERIA
FELT IN	ALGERIA
DETAILS	4 SHOCKS WERE FELT ON THE 17th & 18th Aug AT TENES. THE HOSPITAL & SOME HOUSES WERE CRACKED. THE SHOCK WAS STRONGLY FELT IN THE CHELIFF VALLEY.
SOURCE	11

137.

DATE	AD 1869 Sep 20
EPICENT	36.5N 2.6E
FELT IN	ALGERIA
DETAILS	STRONGLY FELT AT EL-AFFROUN & LA CHIFFA. SEVERAL HOUSES CRACKED AT MOUZAIAVILLE. FELT AT ALGER, BLIDA, MEDEA & CHEBLI
SOURCE	11

138.

DATE	AD 1869 Nov 16 at 12H.45M
EPICENT	34.9N 5.9E - SAHARAN ATLAS, NEAR BISKRA, ALGERIA
INTENS.	9-10
FELT IN	ALGERIA
DETAILS	IN A RADIUS OF 30km FROM THE EPICENTRE, 200 BUILDINGS COLLAPSED & A LARGE NUMBER WERE DAMAGED. CONSIDERABLE DAMAGE IN BISKRA & THE OASES NEARBY. AT SERIANA (1 DEAD) & EL HEBBAB NUMEROUS HOUSES FELL DOWN. AT SIDI OKBA 45 HOUSES COLLAPSED (8 DEAD, 3 INJURED). ONE-THIRD OF THE HOUSES COLLAPSED AT GARTA (2 DEAD, 7 INJURED). HOUSES DAMAGED AT TCHOUDA, DROH, M'CHOUNECHE (4 or 40 DEAD?). STRONG AT BATNA, SLIGHT AT SETIF (150km FROM BISKRA). FROM 16th-20th Nov THERE WERE 11 SHOCKS AT BISKRA. MORE NUMEROUS & WEAKER SHOCKS CONTINUED UNTIL Nov 28
HAZARDS	LANDSLIDES FROM THE ESCARPMENTS ABOVE EL-HEBBAD. THE ROAD FROM M'CHOUNECH TO EDISTA WAS CUT BY LARGE ROCKFALLS FROM THE MOUNTAIN
SOURCE	1,2,6,8,10,11,15,18

139.
DATE AD 1869 Nov 19
FELT IN ALGERIA
DETAILS MAJOR EARTHQUAKE IN INNER ALGERIA. AFFECTED BISKRA. UNKNOWN NUMBER OF DEAD
SOURCE 4
COMMENT SAME AS 138?

140.
DATE AD 1870 Jun 24
EPICENT 32.0N 30.0E - OFF ALEXANDRIA, EGYPT
INTENS. 10-11
MAG. ML 7.2
FELT IN EGYPT, SUDAN, YEMEN P.D.R., TURKEY, SYRIA, ISRAEL, ALBANIA, LIBYA, ITALY, MALTA, CYPRUS, GREECE
DETAILS A LARGE SHOCK THAT WAS WIDELY FELT. FELT ACROSS THE NILE DELTA & ALONG THE LEVANT COASTLINE. AFFECTED BINGHAZI & SOUTHERN ITALY. SEE CATALOGUE 1 FOR DETAILS CONCERNING EASTERN MEDITERRANEAN COUNTRIES
HAZARDS TSUNAMI AT ALEXANDRIA, EGYPT
SOURCE 6,19

141.
DATE AD 1871
FELT IN ALGERIA, SPAIN
DETAILS AFFECTED CORDOBA & ORAN
SOURCE 1

142.
DATE AD 1872 Jul 29 at 8H.45M
EPICENT 35.9N 0.1E
INTENS. 7
FELT IN MOROCCO, ALGERIA
DETAILS SEVERAL HOUSES CRACKED AT MOSTAGANEM. THE BELL TOWER AT MAZAGAN (AL JADIDA) WAS KNOCKED DOWN (INTENSITY =7). THE SHOCK WAS FELT AS FAR AS ORAN & ALGER
SOURCE 6,11,15
COMMENT THE TIME OF THE EVENT WAS 8H ACCORDING TO (6). DUE TO THE DISTANCE BETWEEN AFFECTED AREAS, COULD THIS REPRESENT 2 EVENTS?

143.
DATE AD 1874 Mar 28 or 29 at 11H.10M
EPICENT 36.6N 2.2E
FELT IN ALGERIA
DETAILS AT CHERCHELL NEARLY ALL THE HOUSES WERE CRACKED, CAUSING EVACUATION OF THE INHABITANTS. THE BARRACKS WERE PARTICULARLY AFFECTED (INTENSITY =7). ALSO AFFECTED MILIANA. FELT AT ALGER
SOURCE 1,6,11,15
COMMENT UNCERTAIN DATE. PROBABLY OCCURRED ON THE 28th

144.
DATE AD 1875/76 Mar 23 at 6H.34M
EPICENT 36.5N 2.6E
INTENS. 7
FELT IN ALGERIA
DETAILS HOUSES WERE CRACKED AT EL AFFROUN (INTENSITY =7). VERY STRONG SHOCK AT OUED-DJER (INTENSITY =6) & AT MOUZAIAVILLE, WHERE THE EARTHQUAKE WAS FELT ON A MOVING TRAIN (INTENSITY =6). FELT AT ALGER & MEDEA
SOURCE 6,11,15
COMMENT DATE PROBABLY 1876

145.
DATE AD 1881 Mid-Feb
FELT IN AZORES
DETAILS AFFECTED SAN MIGUEL
SOURCE 1

146.
DATE AD 1881 Jun
FELT IN TUNISIA
DETAILS NUMEROUS STRONG SHOCKS AT GABES & MARETH. THE SHOCKS WERE FELT WITHIN A RADIUS OF 50km. NO DAMAGE
SOURCE 7

147.
DATE AD 1882 May 3
FELT IN AZORES
DETAILS AFFECTED FAYAL
SOURCE 1

148.
DATE AD 1883 Aug
FELT IN LIBYA
DETAILS LARGE SHOCK IN THE REGION OF GUDAMIS. UNKNOWN NUMBER OF DEAD
SOURCE 4

149.
DATE AD 1883 Oct 9
FELT IN ALGERIA
DETAILS AFFECTED SKIKDA, JEMMAPPES (BEN MEHIDI) & STORA
SOURCE 1

150.
DATE AD 1884 Dec 25 at 20H.55M
EPICENT 37.0N 4.0W - BETWEEN GRANADA & MALAGA, SPAIN
INTENS. 10-11
FELT IN SPAIN, MOROCCO
DETAILS AN EARTHQUAKE CATASTROPHE IN ANDALUCIA. A TOTAL OF 17,178 HOUSES WERE DESTROYED IN THE PROVINCES OF GRANADA & MALAGA (AT LEAST 745 DEAD & 1,253 SERIOUSLY INJURED). ALSO FELT IN MOROCCO. INSTRUMENTALLY RECORDED AFTERSHOCKS OCCURRED ON THE 26,27,29,30,31 Dec, 1884 & ON THE 1,5,12 Jan, 1885
SOURCE 6,15,17

151.
DATE AD 1885 Jan 16-17
EPICENT 35.5N 5.7E
INTENS. 8
FELT IN ALGERIA
DETAILS STRONG SHOCK IN THE REGION OF CONSTANTINE, AURES & OULED-BOU-ADJINA (3 HOUSES COLLAPSED). FELT AT BEJAIA, SETIF, BOU SAADA & BORDJ-BOU-ARRERIDJ
HAZARDS GROUND SUBSIDENCE OVER A DISTANCE OF 100m PRODUCED A CREVASSE 8m DEEP AT OULED-BOU-ADJINA, ALGERIA
SOURCE 6,8,11,15

152.

DATE	AD 1885 Jan 30 at 9H.30M
FELT IN	ALGERIA
DETAILS	FELT AT BEJAIA, SETIF, BORDJ-BOU-ARRERIDJ & BOU-SAADA. POSSIBLY AN AFTERSHOCK TO THE EVENT OF 16-17 Jan, 1885
SOURCE	11

153.

DATE	AD 1885 Jan 31
INTENS.	8-9
FELT IN	ALGERIA
DETAILS	AFFECTED M'SILA
SOURCE	1,6

154.

DATE	AD 1885 Dec 3 at 20H.30M
EPICENT	36.1N 4.6E
INTENS.	9-10
FELT IN	ALGERIA
DETAILS	THE SHOCK WAS LARGELY FELT IN A TRIANGULAR AREA BETWEEN GHAZAOUE & COLLO (800km OF COASTLINE), AND GHARDAIA (400km INLAND). THE SHOCK WAS MORE SEVERE IN THE EAST, NOTEABLY AT M'SILA, MASCARA, BOU-SAADA, BLIDA, SETIF, BATNA, MEDEA, BOURUNDA & BORDJ-BOU-ARRERIDJ. AT THE LAST LOCALITY, 40 SHOCKS OCCURRED FROM Dec 3-31 CAUSING CONSIDERABLE DAMAGE. BY May 31, 1886, A TOTAL OF 57 SHOCKS HAD BEEN FELT. THE EPICENTRE WAS PROBABLY CLOSE TO THAT OF THE EARTHQUAKE OF Jan 8, 1887
HAZARDS	ROADS IN THE NEIGHBOURHOOD OF M'SILA WERE RENDERED ALMOST IMPASSABLE BY HUGE BLOCKS OF STONE WHICH ROLLED DOWN FROM THE MOUNTAINS
SOURCE	1,5,6,10,11,15,18

155.

DATE	AD 1886 Jan 29
FELT IN	ALGERIA
DETAILS	AFFECTED SETIF
SOURCE	1

156.

DATE AD 1886 Jul 1 at 9H.45M

EPICENT 36.5N 5.3E - PROBABLY IN THE BABORS, PERHAPS NEAR TO KERRATA, ALGERIA

INTENS. 7?

FELT IN ALGERIA

DETAILS BUILDINGS WERE DAMAGED AT TAKITOUNT (INTENSITY =7). FELT STRONGLY AT SETIF, AND WEAKLY AT JIJEL & BEJAIA. SEVERAL AFTERSHOCKS AT TAKITOUNT DURING THE FOLLOWING DAYS

SOURCE 6,11,15

157.

DATE AD 1886 Sep 9 at 11H.15M

EPICENT 36.2N 3.6E

INTENS. 7

FELT IN ALGERIA

DETAILS STRONGLY FELT AT AUMALE & AIN-BESSEM. 15 ARAB HOUSES, ALREADY IN POOR CONDITION, WERE DESTROYED IN OULED MERIEM & OULED BOUSSAAF

SOURCE 6,11,15

158.

DATE AD 1887 Jan 6

EPICENT UNKNOWN

INTENS. 7-9

FELT IN TUNISIA

DETAILS AN EARTHQUAKE IN TUNIS WHICH CAUSED LIGHT DAMAGE TO A VILLAGE NEAR EJENEL - HOUSES WERE DESTROYED. (4) CITES 7 DEAD AT DJEMMAL (=EJENEL?). (6) REFERS TO AN EVENT ON Jan 5 AT DJEMEL-TUNIS, & ONE ON Jan 6 AT JEMMEL (?)

SOURCE 1,4,6,7

COMMENT PROBABLY DJEMMAL & TUNIS

159.

DATE AD 1887 Jan 8 at 20H

EPICENT 36.1N 4.6E - IN THE BIBANS, WEST OF BORDJ-BOU-ARRERIDJ, PROBABLY NEAR MANSOURAH, ALGERIA

INTENS. 8

FELT IN ALGERIA

DETAILS IMPORTANT DAMAGE AT BORDJ-BOU-ARRERIDJ, WHERE HOUSES & MILITARY BUILDINGS WERE CRACKED

(cont.)

(INTENSITY =7). AT MANSOURAH, 45 ARAB HOUSES COLLAPSED & SEVERAL ADMINISTRATION HOUSES WERE DAMAGED (INTENSITY =8). AT MEDJANA & EL ACHIR SOME WALLS COLLAPSED. THE SHOCK WAS FELT AT SETIF, M'SILA, AZAZGA & PROBABLY BEJAIA. SEVERAL AFTERSHOCKS WERE FELT DURING THE FOLLOWING DAYS, AND THE SHOCKS CONTINUED FOR SEVERAL DAYS AT BORDJ-BOU-ARRERIDJ WHICH FORMED THE CENTRE OF THE SHAKEN ZONE

HAZARDS ROCKFALLS ON THE SOUTHERN SIDE OF THE DALHA MOUNTAINS

SOURCE 6,8,11,15,18

160.

DATE AD 1887 Jun and Nov

FELT IN MOROCCO

DETAILS STRONG SHOCKS AT MELILLA

SOURCE 14

161.

DATE AD 1887 Aug 5

FELT IN ALGERIA

DETAILS AFFECTED LAGHOUAT

SOURCE 1

162.

DATE AD 1887 Nov 29 at 13H.30M

EPICENT 35.6N 0.3E - MOUNTAINS OF BENI-CHOUGRANE, NEAR KALAA, ALGERIA

INTENS. 9-10

FELT IN ALGERIA

DETAILS PRINCIPAL DAMAGE AT KALAA, & IN THE VILLAGES CLOSE TO DEBBA & TLIOUANET. AT KALAA THE MOSQUE & 331 HOUSES WERE DESTROYED (20 DEAD, 5 INJURED, INTENSITY =9-10). AT L'HILLIL THERE WAS SOME CRACKING (INTENSITY =6-7). FELT AT MASCARA, RELIZANE & ORAN

HAZARDS ROCKFALLS & LANDSLIDES IN THE MOUNTAINS OF THE KALAA REGION, BETWEEN MASCARA & MOSTAGANEM. THE VALLEY OF KALAA EXPERIENCED HEAVY LOCALISED ROCKFALLS

SOURCE 2,6,8,11,15,18

163.

DATE	AD 1888 Jan 6 at 23H.40M
EPICENT	36.5N 2.6E
INTENS.	7-8
FELT IN	ALGERIA
DETAILS	HEAVIEST DAMAGE IN FARMS AT THE FOOT OF THE ATLAS, BETWEEN LA CHIFFA & EL-AFFROUN. AT EL-AFFROUN THE CHURCH, SCHOOL & TOWN HALL WERE DAMAGED & A LARGE NUMBER OF HOUSES CRACKED (INTENSITY =8). DAMAGE AT MOUZAIAVILLE, LA CHIFFA & OUED-DJER. SOME CRACKED WINDOWS/CEILINGS AT BLIDA. QUITE STRONG AT ALGER
SOURCE	6,8,11,15
COMMENT	ONE SOURCE CITES Jan 8

164.

DATE	AD 1888 Jan 8
FELT IN	ALGERIA
SOURCE	1
COMMENT	SEE 163

165.

DATE	AD 1889 May 21 at 4H.15M
EPICENT	35.7N 0.8W
INTENS.	7-8
FELT IN	ALGERIA
DETAILS	A VIOLENT SHOCK AT ORAN WHERE CHIMMNEYS COLLAPSED & WALLS CRACKED (INTENSITY =7-8). AFFECTED MERS-EL-KEBIR (AIN-AL-TURCK), TAMZOURA, SIDI-CHAMI & OUED TLELAT. GENERAL ALARM AMONGST THE POPULATION
SOURCE	6,11,15

166.

DATE	AD 1890 Jul 30
EPICENT	35.7N 0.5E
FELT IN	ALGERIA
DETAILS	A VIOLENT EARTHQUAKE WAS FELT AT RELIZANE WHERE HOUSES WERE CRACKED & CEILINGS DAMAGED (INTENSITY =6-7). THIS WAS THE FOURTH EVENT OF THE YEAR
SOURCE	11

167.

DATE AD 1891 Jan 15 at 4H
EPICENT 36.5N 1.8E
INTENS. 10
FELT IN ALGERIA
DETAILS MACROSEISMAL AREA MORE THAN 400km LONG, AVOIDING THE BENI CHOUGRANE MASSIF IN THE WEST & THE DJURDJURA IN THE EAST. AFFECTED THE DAHRA REGION MAINLY. AT GOURAYA 53 HOUSES COLLAPSED & 36 DEAD (INTENSITY =10). AT VILLEBOURG 22 HOUSES DESTROYED (INTENSITY =10) & AT BLIDA SOME HOUSES COLLAPSED. AFFECTED SKIKDA. AT ALGER & EL AFFROUN HOUSES WERE CRACKED. 4 SHOCKS WERE FELT AT ALGER BETWEEN 4H & 6H.45M. FELT AT MIRA, PERREGAUX (MOHAMMADIA), BOGHAR, THENIET-AL-HAD, TIARET, SAIDA, AIN-EL-HADJAR, AIN BESSEM, DJELFA, DJELALA. HOWEVER AIN SEFRA, GERYVILLE (AL BAYADH), LAGHOUAT, AIN-MADHI, BOU-SAADA, BISKRA, TOUGGOURT, GHARDAIA & EL-OUED WERE UNAFFECTED. THE SHOCK WAS NOT FELT AT AUMALE & BOUIRA
HAZARDS AT VILLEBOURG, A CRACK 40cm WIDE CROSSED THE VILLAGE. AT MOUZAIAVILLE AN EARTHSLIDE CUT THE ROAD. INVESTIGATORS RECOMMENDED THAT VILLEBOURG OUGHT NOT TO BE REBUILT ON THE SAME SITE DUE TO THE NATURE OF THE GROUND & FREQUENT LANDSLIDES PERPENDICULAR TO THE SEA. ROCKFALLS OCCURRED FROM THE MOUNTAIN PEAKS OF L'OUARSENIS IN THE LOCALITY OF GOURAYA. ONE ROCK OVERHANG COLLAPSED CRUSHING A HOUSE AND KILLING THE INHABITANTS. THE LEVEL OF THE COASTLINE ROSE MORE THAN 30cm IN PLACES
SOURCE 1,2,6,8,10,11,15,18

168.

DATE AD 1891 Jan 16 at 2H.15M
FELT IN ALGERIA
DETAILS A QUITE STRONG SHOCK AFFECTED DJURDJURA, & WAS FELT AT OUED AMIZOUR, KHERRATA & JEMMAPES (AZZABA). THE SHOCK PROBABLY HAD AN EPICENTRE TOTALLY DISTINCT FROM THAT OF THE Jan 15 EVENT
SOURCE 11

169.

DATE	AD 1894 Jun 19
FELT IN	ALGERIA
DETAILS	AFFECTED ORAN
SOURCE	1

170.

DATE	AD 1894 Sep 19 at 6H.40M
EPICENT	UNCERTAIN
FELT IN	ALGERIA
DETAILS	STRONG SHOCK AT CONSTANTINE
SOURCE	11

171.

DATE	AD 1895 Jul 18 at 23H
EPICENT	UNKNOWN
FELT IN	ALGERIA
DETAILS	SHOCK FELT AT ALGER IN THE NAVAL QUARTER. PANIC STRICKEN INHABITANTS RAN OUT INTO THE STREET (INTENSITY =6)
SOURCE	11

APPENDIX B2

INDEX TO COUNTRIES LISTED IN THE CATALOGUE

Each record in the historical catalogue has a number. The records referring to particular countries and islands are listed below:-

APPENDIX B3

INDEX TO HAZARDS OTHER THAN EARTHQUAKES IN THE CATALOGUE

The records referring to hazards associated with earthquake events are as follows:-

FAULTING

7 59 131

LANDSLIDES

12 41 59 78 91 113 138 162 167

LIQUEFACTION/SUBSIDENCE

12 59 78 114 115 151

ROCKFALLS

15 51 115 131 138 154 159 162 167

TSUNAMI

4 15 26 29 31 51 52 64 67 72 76 115 140

VOLCANIC ERUPTION

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APPENDIX B4

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